CONNECTICUT DEPARTMENT OF TRANSPORTATION
Reconstruction of I-84
Washington Avenue to Pierpont Road
Waterbury, CT
ConnDOT Project No. 151-273
Federal Aid Project No. NHI-84-2 (172) 33

FINAL SCOUR REPORT
BRIDGE NO. 06591

EXIT 24 ON-RAMP TO WESTBOUND I-84 OVER THE MAD RIVER

Waterbury, Connecticut
New Haven County

Prepared By:

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July 2006
Revised May 2014

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Executive Summary

This scour report has been prepared for the final design of proposed Bridge No. 06591, the proposed new Exit 24 On-Ramp to Westbound I-84 from Harpers Ferry Road at Exit 24. This crossing is one of six (6) waterway crossings over the river to be constructed under the State Project No. 151-273, improvements to Interstate 84 in Waterbury from Washington Avenue east to Pierpont Road. The subject 4.3-kilometer (2.7 mile) long highway project has been designed by Ammann & Whitney (formerly Berger, Lehman Associates, P.C. – BLA).

The new crossing is located within the limits of a proposed relocation of the Mad River. Presently, a westbound on-ramp at Interchange 24 does not exist. The proposed structure will carry a new on-ramp to I-84. It will be located at the approximate location of the downstream face of existing Structure No. 05774 (easterly I-84 crossing over the Mad River). The proposed bridge will be on a curved alignment with a substructure consisting of concrete abutments founded on end bearing steel H-piles terminating in glaciofluvial deposits.

The bridge will be within the reach of the Mad River proposed to be channelized (12 m bottom width with 2H to 1V side slopes). The bridge abutments have been located to minimize obstruction of flood flows for discharges up to and including the 500-year event. Therefore, the proposed structure does not cause any significant upstream backwater conditions for the 100-year design flood. In addition, the superstructure is elevated well above the channel with a minimum underclearance of 4.5 m (14.7 ft) at the downstream face during the 100-year design event, and 3.5 m (11.5 ft) of underclearance for the 500-year event.

This report finds that the proposed bridge will experience the greatest potential scour during the 500-year event. The computations indicated the depth of scour at the bridge could be as much as 1.73 m (5.7 ft), which still does not expose the piles supporting the substructure. The analysis is based on the existing streambed material that is found in the vicinity of the proposed bridge. The proposed channel under the bridge will, however, have Standard Riprap on the banks providing the added protection.

Table 1. NBIS Ratings and Scour Related Design Information

Recommended NBIS Item 113 Rating	8 (for 100-year design discharge)
Recommended NBIS Item 71 Rating	9
Recommended NBIS Item 61 Rating	8
Scour Risk Designation	Low Risk
Depth of Potential Scour (500-year)	1.73 m (Abutment #1 – West); 1.51 m (Abutment #2 – East)
Foundation Type	Abutment Footings on Piles
Recommendations	Foundation Designed for Predicted Scour Depth

Reference Reports

The following reports, prepared under separate covers for the project, should be referenced for more detailed information pertinent to the hydrology and hydraulics for the subject reach of the Mad River and the hydraulic design of Bridge No. 06591.

- *Overview Report for Hydraulic Design, CT DEP Flood Management Certification & FEMA Conditional Letter Of Map Revision (CLOMR), Mad River & Beaver Pond Brook, Waterbury, Connecticut* prepared by ConnDOT, July 2006.
- *Hydrologic Report, Mad River* prepared by BLA, September 1999
- *Hydraulic Analysis for Design Report, Mad River* prepared by ConnDOT, revised April 2014.
- *Final River Relocation Report, Mad River & Beaver Pond Brook* prepared by BLA, January 2004 and revised by ConnDOT, April 2006.
- *Mad River Floodplain/Floodway Analysis Report for FEMA CLOMR & CTDEP Flood Management Certification* prepared by ConnDOT, revised April 2014.

Project Overview

The information presented in this report are derived from the hydraulic analyses performed using the DOT "Design" discharges as presented in the *Hydraulic Analysis for Design Report, Mad River* prepared by ConnDOT, revised April 2014. For complete hydrologic information refer to *Hydrologic Report, Mad River* prepared by BLA (Ammann & Whitney), September 1999. The summarized hydrologic information is shown in the table below.

Table 2. Hydrologic Information

Watershed Area:	62.26 km^2 (24.04 mi^2)- Large Structure
Discharges:	100-Yr: 176.98 cms (6,250 cfs)
	500-Yr: 269.01 cms (9,500 cfs)
	Overtopping: >500 year

See the Overview Report referenced above for an overview of the project, the existing and the proposed project conditions.

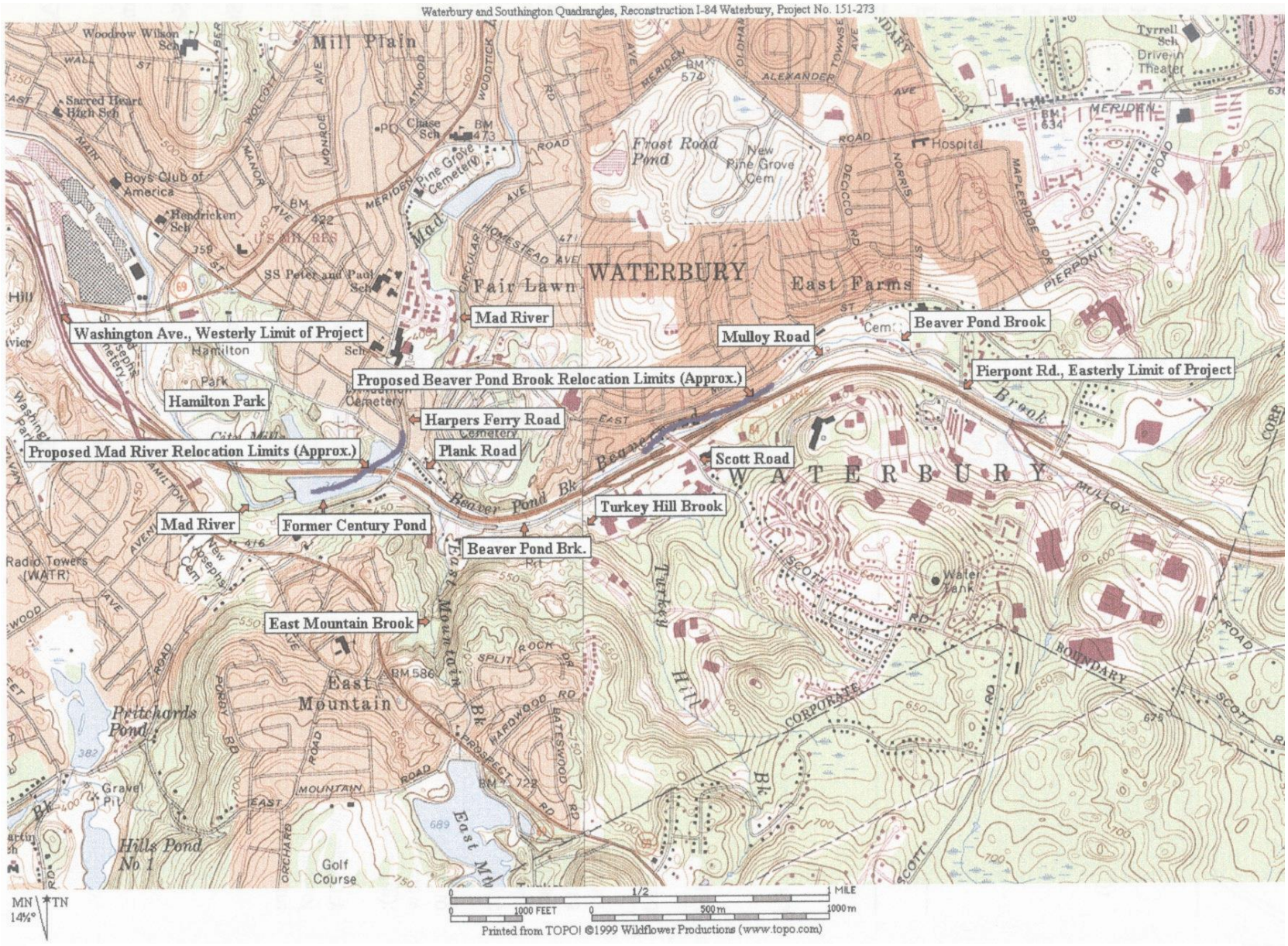


FIGURE 1 - PROJECT LOCATION PLAN

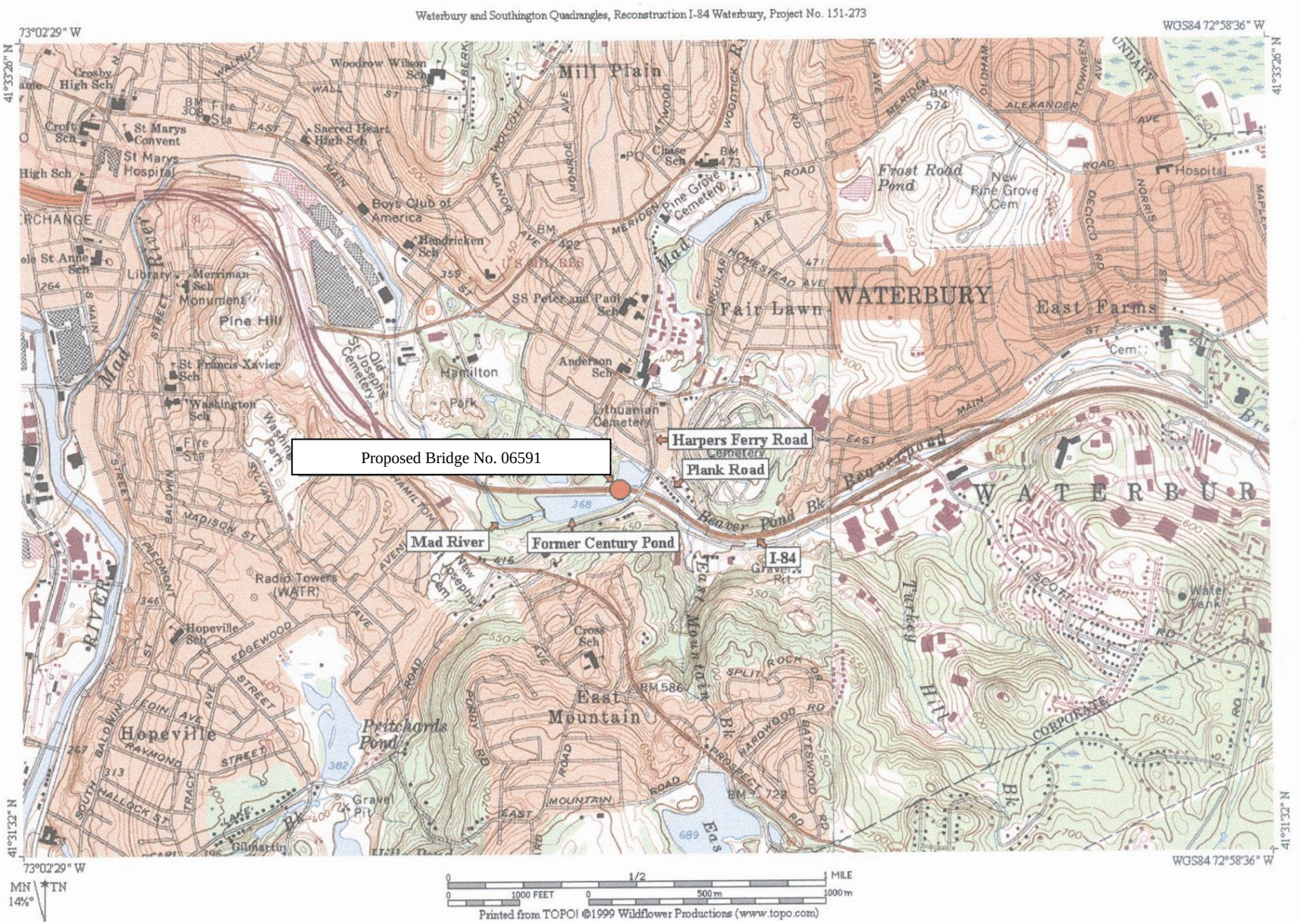


FIGURE 2 - STRUCTURE LOCATION PLAN

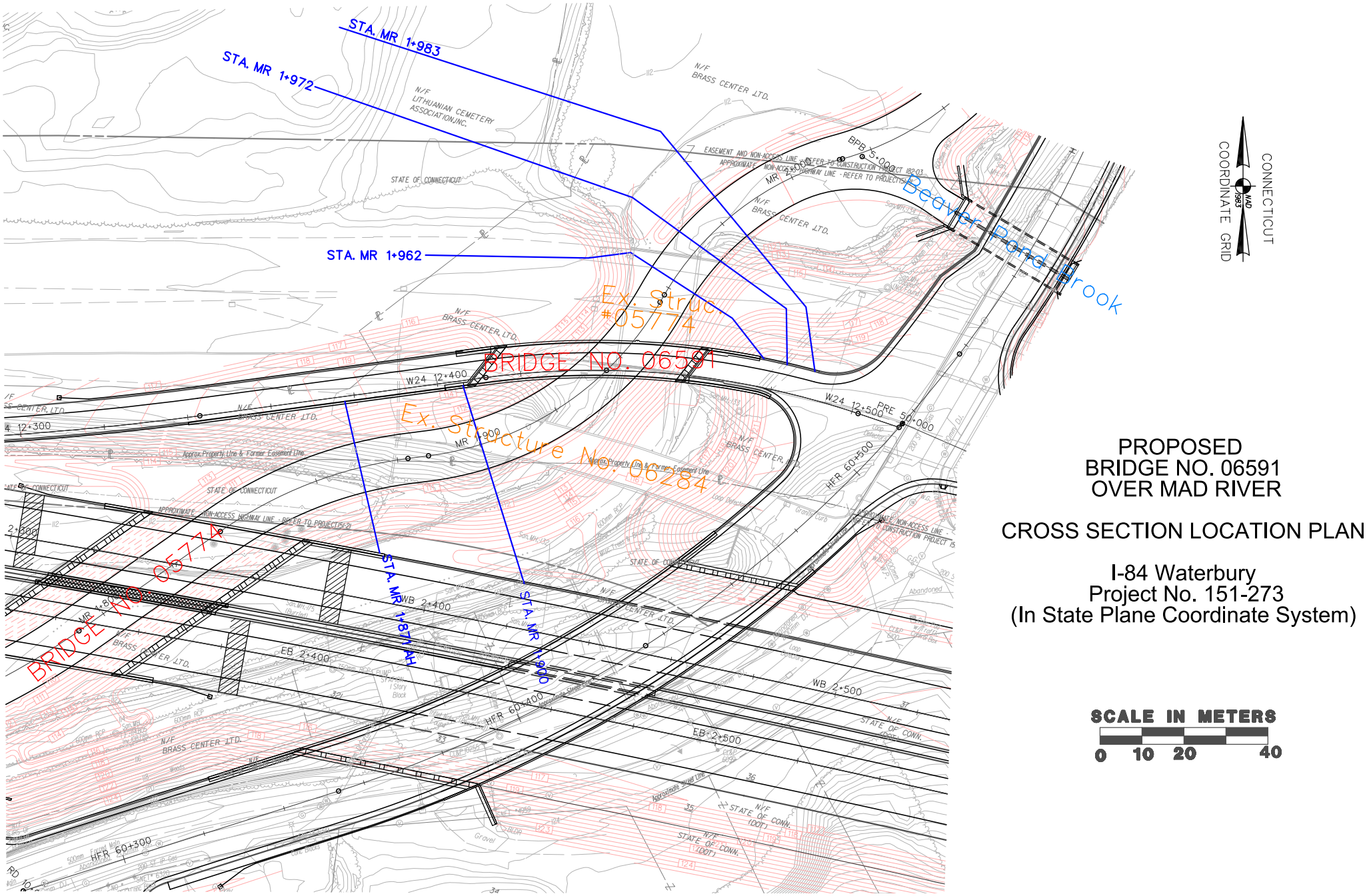


FIGURE 3 - CROSS SECTION LOCATION PLAN (VICINITY OF BRIDGE)

Report Background

This scour report with the accompanying final hydraulic report have been prepared as part of the final design for Bridge No. 06591, the Exit 24 On-Ramp to Westbound I-84 over the Mad River. Presently, there is no westbound on-ramp at Interchange 24. The new crossing is located within the limits of a proposed relocation of the Mad River. .

Scour depths have been estimated following procedures set forth by the Federal Highway Administration in Hydraulic Engineering Circular No. 18 (HEC-18), *Estimating Scour at Bridges*, May 2001. As recommended on page 9.B-2 of the *2000 ConnDOT Drainage Manual*, the following Amended Local Abutment Scour Equation was utilized:

$$Y_s/Y_a = [2.27\ K_1\ K_2\ (L'/Y_a)^{0.43}\ Fr^{0.61}] + 0.05 \qquad \text{(ConnDOT)}$$

This equation predicts scour depths for the 50th percentile as compared to the more conservative HEC-18 version of Froehlich's equation (equation 7.1, page 7.8), which would have encompassed 98% of the laboratory produced scour holes from the original study. The HEC-18 version of Froehlich's equation is as follows:

$$Y_s/Y_a = [2.27\ K_1\ K_2\ (L'/Y_a)^{0.43}\ Fr^{0.61}] + 1 \qquad \text{(HEC-18)}$$

A comparison of the two local abutment equations shows that ConnDOT's version will predict scour depths $0.95Y_a$ less than proposed by HEC-18. Y_a is the average depth of floodplain flow at the upstream approach cross section.

The discharges used in this investigation have been approved by ConnDOT and are presented in the September 1999 *Hydrologic Report, Mad River, Waterbury, Connecticut* prepared by BLA (Ammann & Whitney). The discharges reported in the original 1979 and currently effective 2013 Waterbury Flood Insurance Study are 25-30% lower than those approved by ConnDOT.

The hydraulic analysis completed for this investigation utilized HEC-RAS version 4.1.0 assuming mixed flow conditions. A CD containing the HEC-RAS data files is included in the referenced *Hydraulic Analysis for Design Report, Mad River*.

Proposed Bridge

Proposed Bridge No. 06591 will be a single span bridge on a curved alignment with a clear span of approximately 48 meters (157 feet) measured along the roadway baseline between the abutment faces. It will carry the Exit 24 On-Ramp to I-84 Westbound over the Mad River. This will be a new on-ramp from Harpers Ferry Road, as it is not included in the existing interchange.

The location of the proposed bridge is approximately at the downstream face of existing Structure No. 05774, which is the existing easterly I-84 crossing over the Mad River. Due to the proposed 60-meter (200-ft) southerly shift of the Interstate to improve horizontal alignment in this area, the easterly I-84 crossing will be relocated approximately 150 meters (490 ft) downstream (along relocated river) from its present location. In the hydraulic analysis, the Bridge No. 06591 is located at River Station 1938.5 in the Proposed Condition model only.

The width of the structure, perpendicular to the roadway baseline, will be 8.9 meters (29.2 ft). The roadway will be at a 45° skew to the river baseline. To account for this skew and the curved alignment, the proposed conditions analysis assumed the hydraulic clear span of the structure to be 28.65 meters (94 ft - downstream end; wider at the upstream end). The bridge abutments were located so that they will not obstruct flow during the 100-year design discharge. Therefore, the proposed crossing does not cause any significant upstream backwater condition for the 100-year flood. In addition, the superstructure is elevated well above the channel with a minimum underclearance of approximately 4.5 meters (at the downstream-westerly end of the bridge) during the 100-year design event.

Although the flood flows up to the 100-year discharge will not be obstructed by the bridge abutments, significant contraction of flow will occur approximately 30 meters upstream of the proposed crossing. The degree of contraction will certainly be less than the existing condition with the removal of the I-84 Structure No. 05774 from its current location; nonetheless, because of the remnants of the existing I-84 embankment, the flood flow will continually be forced to reduce its width drastically - from 133 meters (436 ft) near the confluence with the Beaver Pond Brook (RS 2020) to 32 meters (105 ft) where the former City Mill Pond narrows to the channelized river section. According to the hydraulic analysis, the 100-year flow velocity increases from 1.2 m/s (3.9 ft/s) at RS 2020 to 2.1 m/s (6/9 ft/s) at the beginning of the channelized section (RS 1962), then to 2.9 m/s (9.5 ft/s) through the bridge opening. The 500-year flow velocity through the bridge will be 3.1 m/s (10.1 ft/s).

In order to provide stable banks, the channel will be reconstructed with Standard Riprap revetment having 2H to 1V side slope, and the bottom width of 12 meters (40 feet). This defined channel extends 30 meters (100 ft) upstream of the new bridge, to the existing contraction point described earlier. This distance was intentionally incorporated into the design, as it was estimated being the minimum length according to the design criteria for guide banks as presented in *Bridge Scour and Stream Instability Countermeasures*, HEC-23, March 2001. Similar to

bridges protected by guide banks, the channel extension will move the scour that normally occurs at the bridge to a new location upstream of the crossing. This location will be sufficiently upstream so as not to affect the bridge foundation. At the entrance to this channel extension, significant scour could develop due to the narrowing of the floodplain width as described above. To reduce potential scour depths and headcutting in this location, an extended length grade control structure consisting of rounded stone riprap will be installed along the channel invert between stations MR 1+940 and 1+970.

The new channel construction will extend 270 meters (885 ft) downstream from the proposed bridge, which is encompassed within a 520-meter (1,706-ft) reach of the Mad River proposed being relocated and reconstructed under this project. This extended downstream channel construction has been incorporated to address instability of the existing channel. The proposed bridge site falls within the reach of the Mad River affected by the 1998 partial breach of Century Dam, which is located approximately 390 meters (1,280 ft) downstream of the existing Structure No. 05774. Prior to the breach, City Mills Pond extended upstream through the existing I-84 crossing (Structure No. 05774), terminating approximately at the downstream side of the next upstream roadway crossing (Plank Road Structure No. 05668). After draining the pond, the channel immediately upstream of the breached dam was apparently provided with riprapped channel banks for a length of approximately 130 meters (425 ft). Upstream of this segment to roughly the midpoint between the existing Structures No. 06284 (Eastbound Exit 25 Off-Ramp crossing) and No. 05774, the existing channel shows signs of erosion along the riverbanks displaying lateral instability of the river caused by the breach. The riverbanks are actively eroding, forming several shallow meanders. The erosion is beginning to encroach into a reported bulky landfill site which was apparently active during the dam breach project. The source of the landfill material is purportedly from the development of the Brass Mill Mall site in Waterbury. Anyway, the new channel limit will connect to the previously placed riprap protection; and as a complete, continuous stable channel, it should eliminate the existing erosion problem and the lateral instability of the river.

The overall vertical profile of the relocated channel will be maintained by a series of strategically placed riprap grade control structures. The general concept of the grade control structures is from the 1986 Swiss publication *Blockschwellen* (Block Ramps) by Whitttaker and Jäggi. These structures will serve as hard-points along the channel bottom to limit channel headcutting. Between the grade control structures, 600mm (24 in.) of Gravel Streambed Material will be placed along the channel invert to simulate a "natural" riverbed. This substrate will maintain the continuity of sediment supply through the reach, similar to a natural channel. The gravel material will also serve as a foundation for the development of a diverse and productive aquatic habitat.

Scour Potential Assessment and Results

Scour computations were completed for the 100- and 500-year frequency discharges. The computations for the lower frequency discharges were not performed as the degree of contraction, velocity and other flow variables were found relatively moderate compared to the conditions under the above high frequency discharges.

The D_{50} used in the presented computation was based on a soil sample of existing material taken in the vicinity of the proposed bridge (see Figure 4). The bottom of the proposed channel will actually be laid with Gravel Streambed Material which is intended as sediment supply medium, as indicated previously. However, the composition, thickness and the relative vertical location of this layer will change over time, as it is displaced and replenished with the sediment supply from upstream - mainly until the proposed channel stabilizes, and a balance in sediment transport is established. Moreover, as the median particle size of the proposed channel-bed material is larger than that of the soil sample, the d_{50} used in the computation is deemed to produce more conservative results.

Figure 4. Soil Sample (For estimating D_{50} for Scour Analysis)

Scour analysis Soil Sample #3, upstream of existing I-84 Structure No. 05774, easterly riverbank looking westerly, location upstream of proposed Bridge No. 06591, 12/7/00

The computed scour depths are minimal because the abutments have been located to minimize the obstruction of overbank floodplain flows and the river channelization moves the contraction of flow away from the structure.

Computed scour depths for the 100 and 500 year return frequencies are as follows:

Table 3. Summary of Computed Scour Depths

100 Year	Scour Depths (m)			
	Long-Term	Contraction	Amended Abutment	Amended Total
Abutment 1(Westerly)	0.3	0.25*	0.00	0.55
Abutment 2(Easterly)	0.3	0.25*	0.00	0.55

500 Year	Scour Depths (m)			
	Long-Term	Contraction	Amended Abutment	Amended Total
Abutment 1(Westerly)	0.3	0.75*	0.68	1.73
Abutment 2(Easterly)	0.3	0.75*	0.47	1.52

* *Further upstream of the bridge where the river channel narrows to the new trapezoidal section, the contraction scour is greater at 1.94 m for the 100-year, and 2.27 m for the 500-year discharges.*

The 100-year discharge was determined to be the design discharge.

Long-term channel scour was assumed to be 0.3 meter (one foot) to account for potential future channel degradation and will largely be controlled by the proposed riprap grade control structures. As discussed previously, the general concept of the grade control structures is from the publication *Blockschwellen* by Whittaker and Jäggi. The design assumes that the structures will act as hard-points along the channel bottom to limit channel headcutting. As scour holes develop downstream of the grade control structures, rocks from the grade control structures will launch into the scour holes. Eventually, an equilibrium will be reached when a sufficient quantity of stone has been launched into the scour holes, completely armoring the holes, and preventing further channel degradation. The volume of the constructed grade control structure must be sufficient to provide enough rock to launch into the scour hole to an adequate depth to armor the scour hole and still provide grade control protection in its constructed location. The thickness of the proposed grade control structure (River Station 1+940 to +970) upstream of the bridge is 0.9 meter (2 ft). It is assumed that the anticipated launching of the rocks could reduce the thickness of the grade control structures by as much as 0.3 meter (one foot) and result in a corresponding lowering of the constructed channel profile (long-term channel degradation). Further vertical degradation will be restricted by the additional downstream grade control structures at River Stations 1+860, 1+775 and 1+695, of which each will be 2-meter (6.6-ft) thick .

Structural Design Review and Conclusions

Footing
Page 2.4 of HEC-18 states:

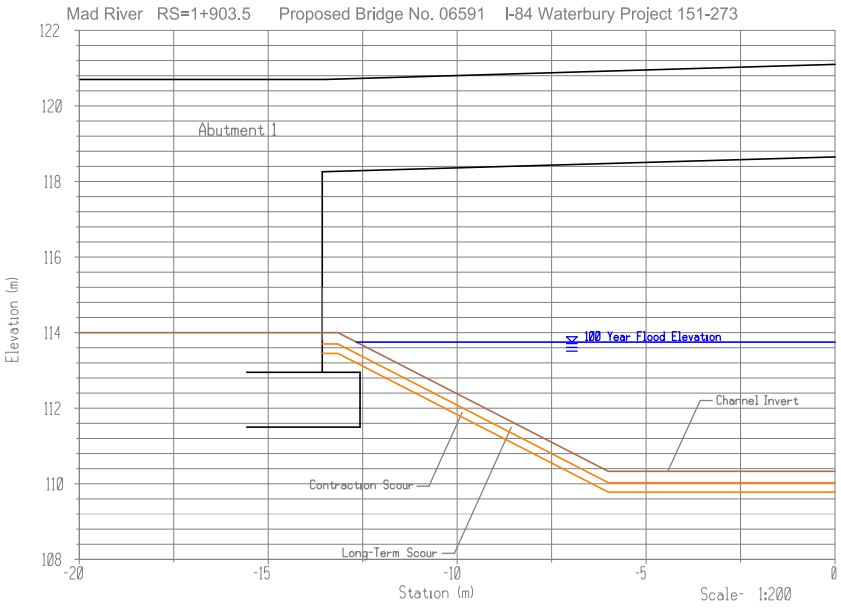
> Placing the top of the footing or pile cap below the streambed a depth equal to the estimated long-term degradation and contraction scour depth will minimize obstruction to flood flows and resulting local scour.

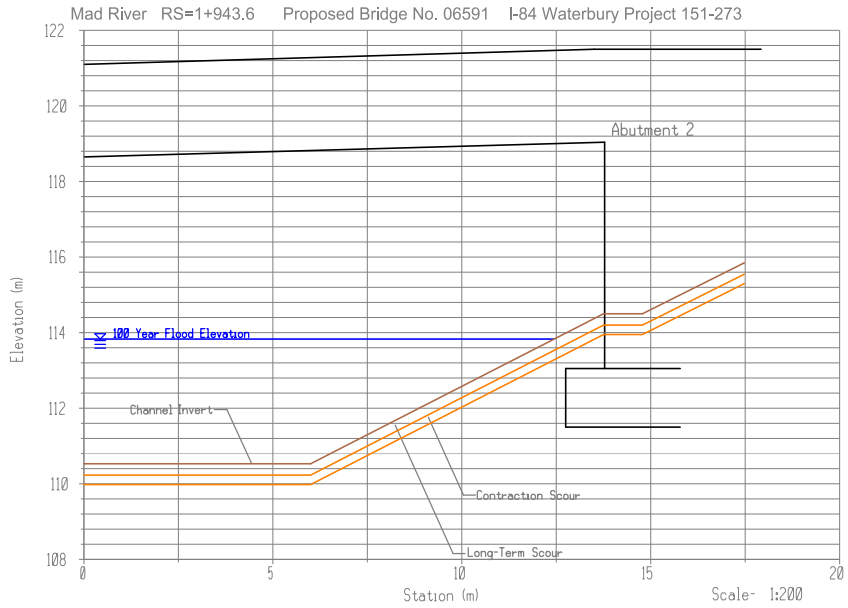
The top of the pile cap has been located in accordance with this guideline for the 100-year design discharge.

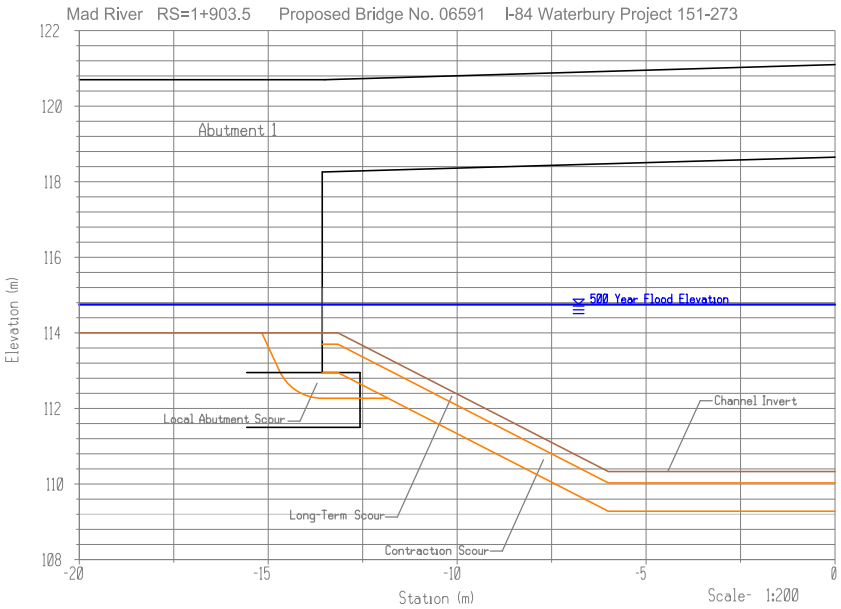
Piles
The typical guideline for pile supported abutments is to design the substructure using normal factors of safety assuming the piles are unsupported to the depth of total scour (long-term plus contraction plus amended local abutment) for the design discharge. The calculations indicate that the depth of total scour will not expose the piles for the 100-year design discharge.

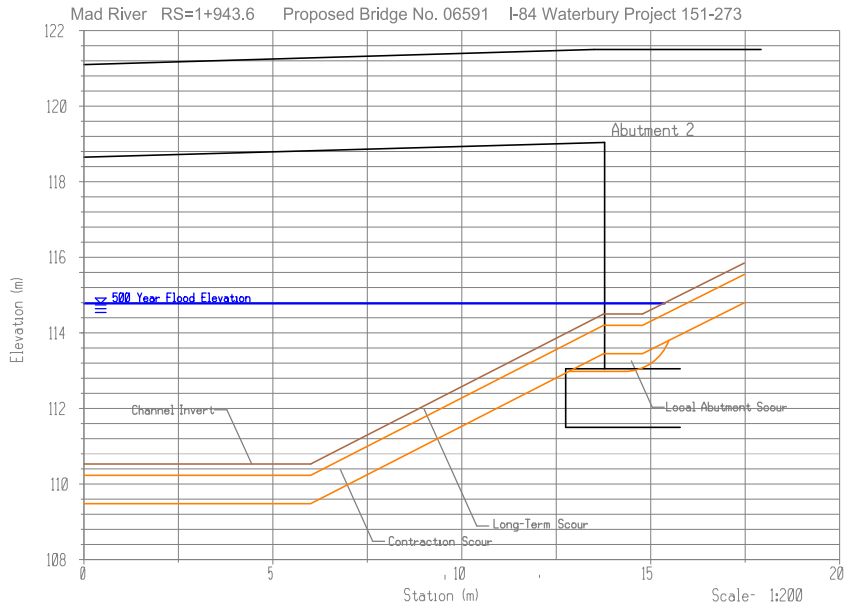
"Superflood"
Page 2.4 of HEC-18 recommends that the foundation design should be checked for scour conditions resulting from a "Superflood". The design "should have a minimum factor of safety of 1.0 (ultimate load) under the superflood conditions." For this bridge the 500-year flood was assumed to be the "Superflood". As with the 100-year design discharge, the computations predict that the piles will not be exposed by scour during the 500-year event.

Figure 5. Scour Depth Cross Sections



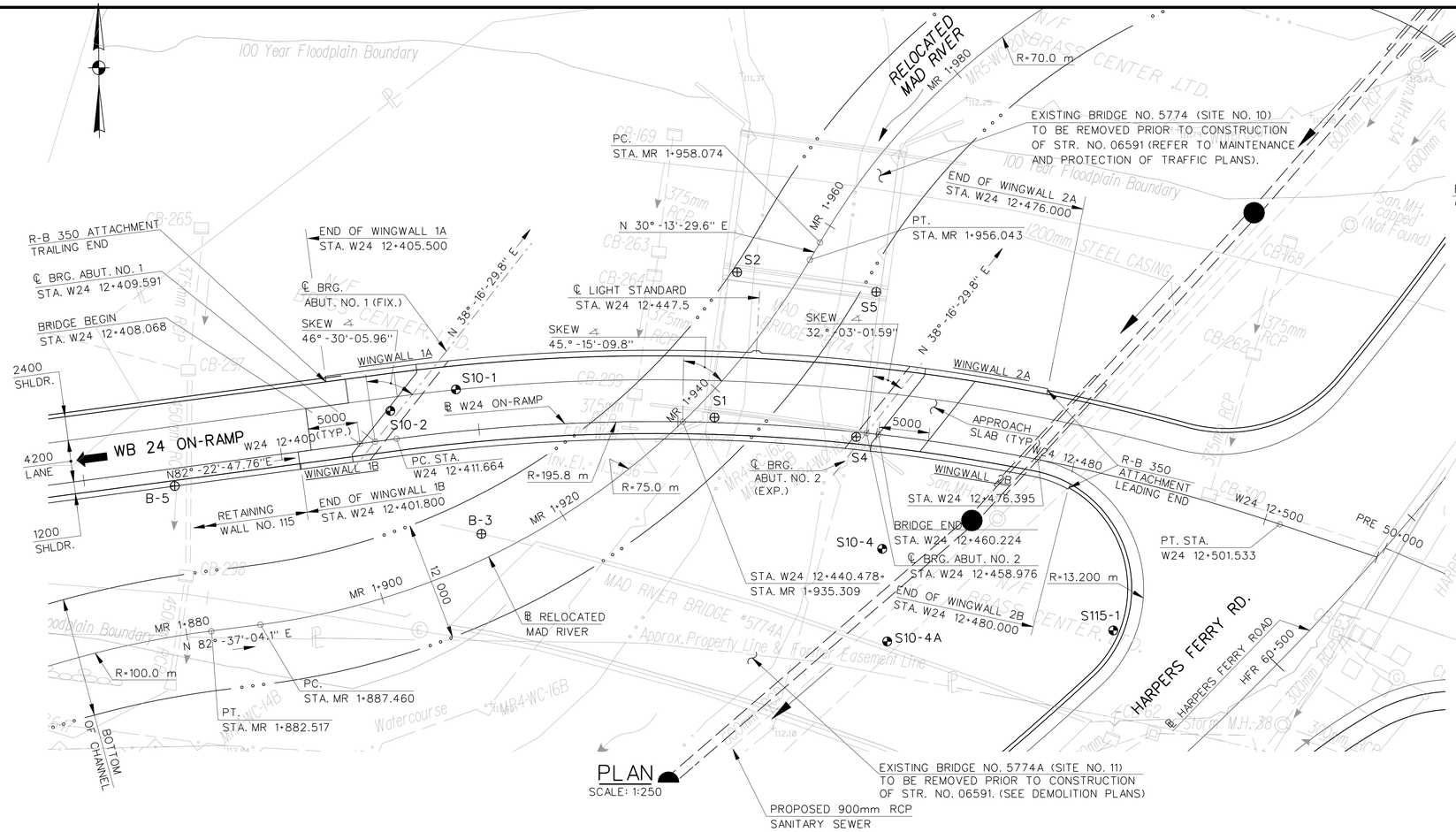






Appendix A: Structure Plans & Details

(Note: The plans and details included in this report are intended for information purposes only. If there are any discrepancies to the actual construction or "as-built" plans, the information reflected on the construction or "as-built" plans shall be construed more accurate.)



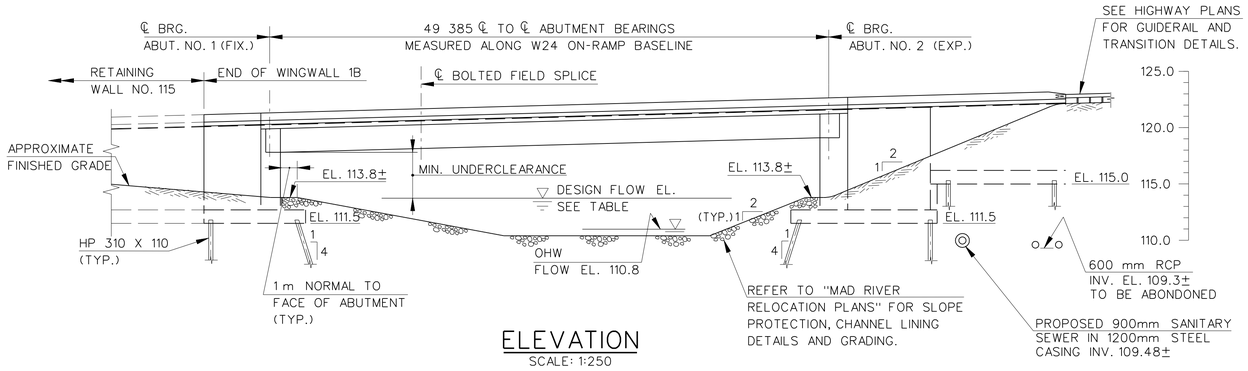
PLAN
SCALE: 1:250

W24 ON-RAMP	
P.C.	STA. W24 12+411.664
	N 230887.847
	E 283043.838
P.T.	STA. W24 12+501.533
	N 230879.264
	E 283132.506
Δ	26°-17'-52.6"
R	195.800 m
T	45.741 m
L	89.869 m

MAD RIVER	
P.C.	STA. MR 1+887.460
	N 230869.187
	E 283030.172
P.T.	STA. MR 1+956.043
	N 230905.811
	E 283085.340
Δ	52°-23'-34.6"
R	75.000 m
T	36.899 m
L	68.582 m

CURVE DATA

TRANSPORTATION DIMENSION AND MASS				
MEMBER	MAX. SHIPPING LENGTH	MAX. SHIPPING HEIGHT	MAX. SHIPPING WIDTH	MAX. SHIPPING MASS
G-4	36 200 mm	2400 mm	1500 mm	25 900 kg



ELEVATION
SCALE: 1:250

BORING LEGEND

- NEW BORING (2001)
- EXISTING BORING (1957 AND 1991)

BRIDGE/CULVERT NO.	06591
Drainage Area, km2	62.3
Design Frequency, year	100
Design Discharge, cms	176.98
Average Daily Flow Elevation, M	110.8 (observed)
Upstream Design Water Surface Elevation, M	113.83
Downstream Design Water Surface Elevation, M	113.78
Maximum Scour Elevation, M	112.27
Frequency (year)	500
Discharge (cms)	269.01
Worst case scour sub-strucutre unit	Abutment #1 (West)

THE INFORMATION, INCLUDING ESTIMATED QUANTITIES OF WORK SHOWN ON THESE SHEETS IS BASED ON LIMITED INVESTIGATIONS BY THE STATE AND IS IN NO WAY WARRANTED TO INDICATE THE TRUE CONDITIONS OR THE ACTUAL QUANTITIES OR DISTRIBUTION OF QUANTITIES OF WORK WHICH WILL BE REQUIRED.

REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

DESIGNER: C. ADAMS
DRAFTER: M. MOSLEY
CHECKED BY: B. YIN
DATE CHECKED: 12/2013

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

CADD ...\Str10\FD\0273F10001.BRG
PLOTTED 5/21/2014

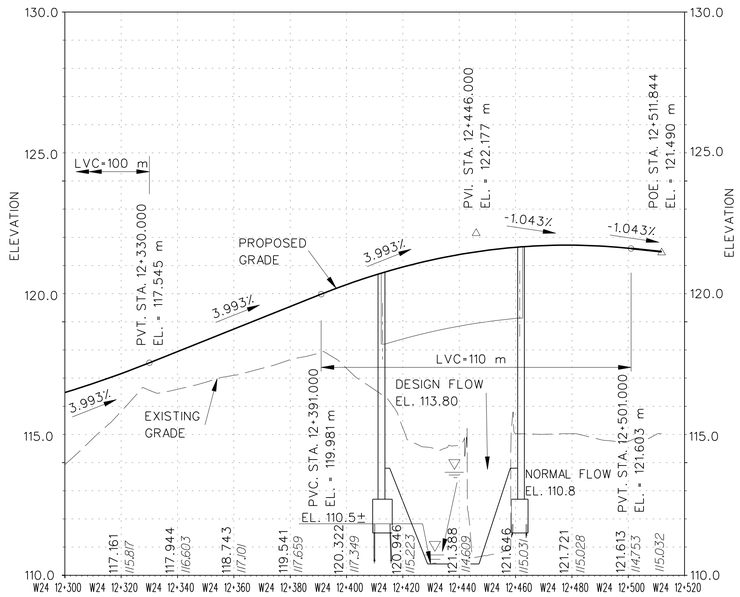
AMMANN & WHITNEY
2500 WESTCHESTER AVENUE
3RD FLOOR
HARRISON, NY

PROJECT TITLE:
RECONSTRUCTION OF I-84 WATERBURY
WB W24 ON-RAMP OVER MAD RIVER
STRUCTURE NO. 151-273-06591

TOWN: WATERBURY

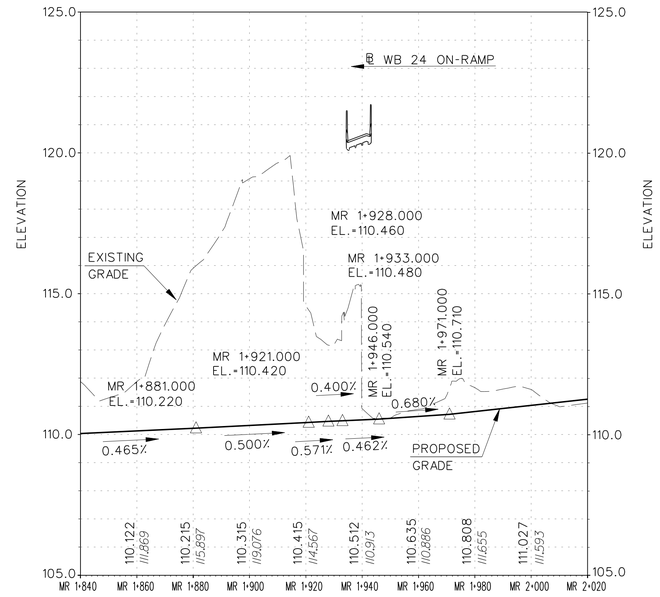
DRAWING TITLE: GENERAL PLAN AND ELEVATION

PROJECT NO.: 151-273
DRAWING NO.: S 1
SHEET NO.: 05.08.001



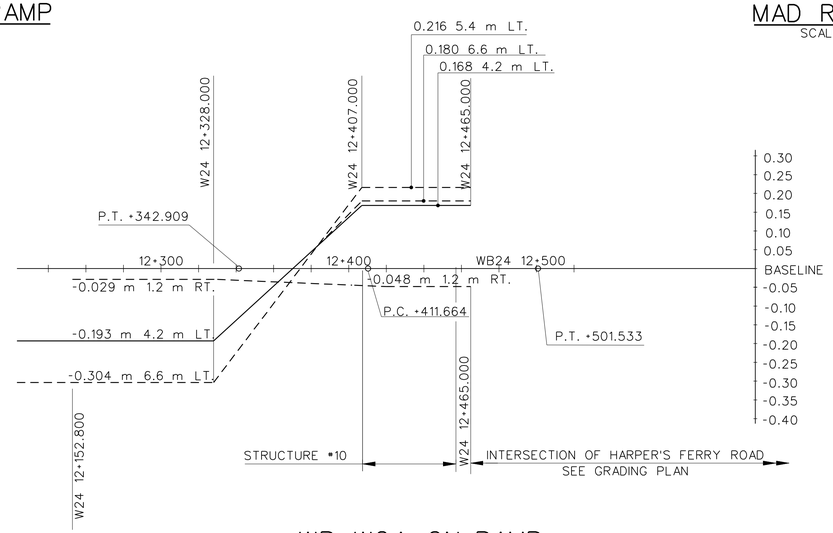
PROFILE WB 24 ON-RAMP

SCALE: HORIZ. 1:1000
VERT. 1:100



MAD RIVER PROFILE

SCALE: HORIZ. 1:1000
VERT. 1:100



WB W24 ON-RAMP SUPERELEVATION DIAGRAM

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REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

DESIGNER: C. ADAMS
DRAFTER: M. MOSLEY
CHECKED BY: B. YIN
DATE CHECKED: 12/2013

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

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PLOTTED 12/4/2013

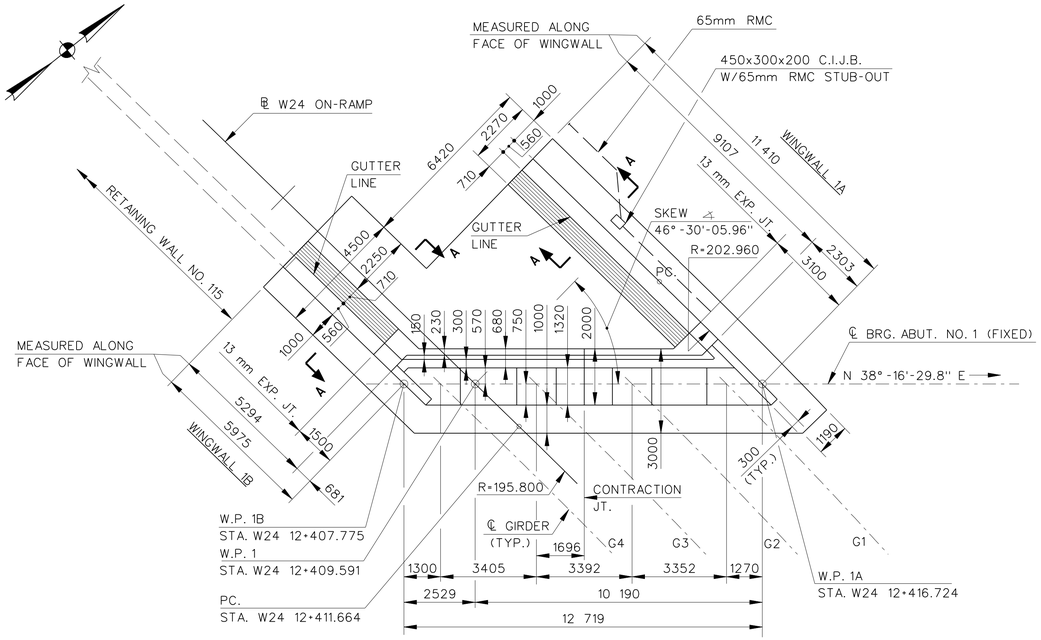
AMMANN & WHITNEY
2500 WESTCHESTER AVENUE
3RD FLOOR
HARRISON, NY

PROJECT TITLE:
RECONSTRUCTION OF I-84 WATERBURY
WB W24 ON-RAMP OVER MAD RIVER
STRUCTURE NO. 151-273-06591

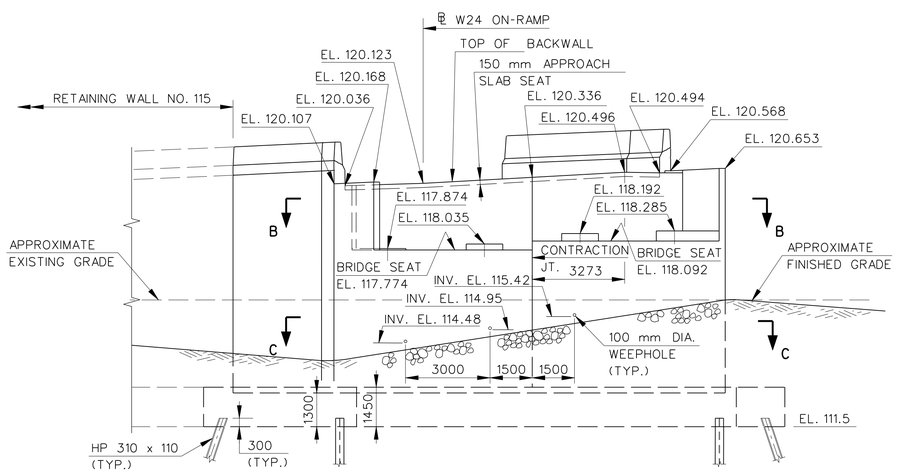
TOWN: WATERBURY

DRAWING TITLE: PROFILES

PROJECT NO.: 151-273
DRAWING NO.: S 5
SHEET NO.: 05.08.005



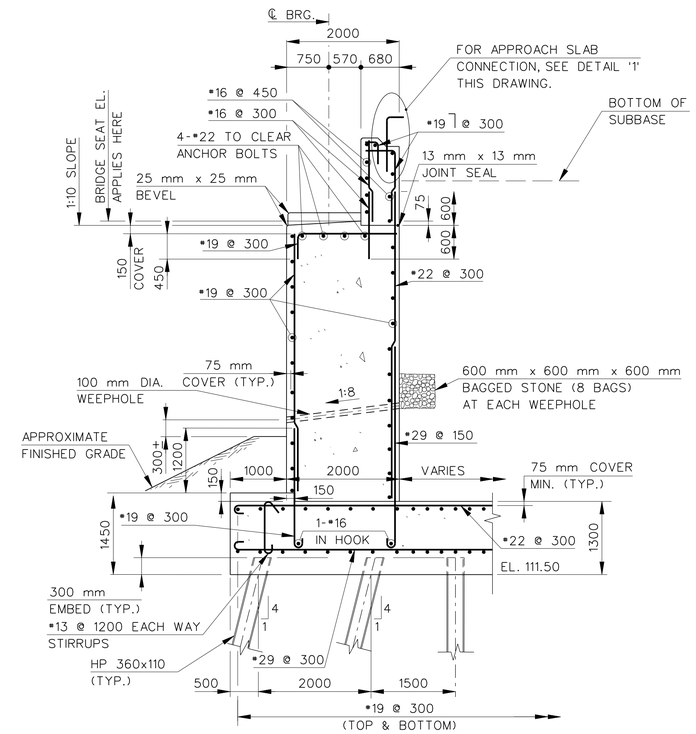
PLAN



ELEVATION

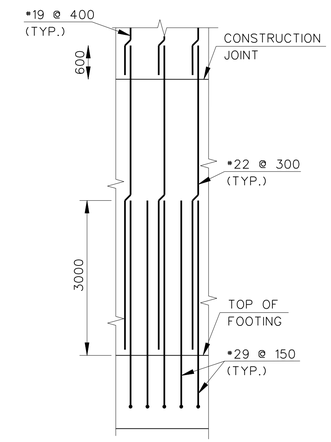
ABUTMENT 1

SCALE: 1:100

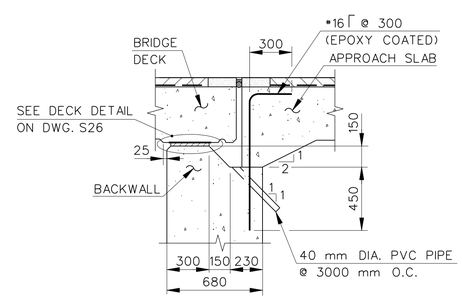


TYPICAL SECTION - ABUTMENT 1

SCALE: 1:50



REAR FACE



DETAIL '1'

SCALE: 1:20

NOTES

1. FOR WORKING POINT (W.P.) COORDINATES, SEE STR. DWG. S3.
2. FOR WINGWALL ELEVATIONS, SEE STR. DWG. S15
3. FOR SUBSTRUCTURE DETAILS, SEE STR. DWG. S17.
4. FOR SECTION "A-A", SEE STR. DWG. S16.
5. FOR SECTIONS "B-B" AND "C-C", SEE STR. DWG. S12.
6. FOR MAX. DESIGN PILE LOAD, SEE 'FOOTING AND PILE PLAN' DRAWING NO. S9.

THE INFORMATION, INCLUDING ESTIMATED QUANTITIES OF WORK SHOWN ON THESE SHEETS IS BASED ON LIMITED INVESTIGATIONS BY THE STATE AND IS IN NO WAY WARRANTED TO INDICATE THE TRUE CONDITIONS OR THE ACTUAL QUANTITIES OR DISTRIBUTION OF QUANTITIES OF WORK WHICH WILL BE REQUIRED.

REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

DESIGNER: C. ADAMS
DRAFTER: M. MOSLEY
CHECKED BY: B. YIN
DATE CHECKED: 12/2013

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

CADD ...\Str10\FD\0273f10010.brg
PLOTTED 4/7/2014

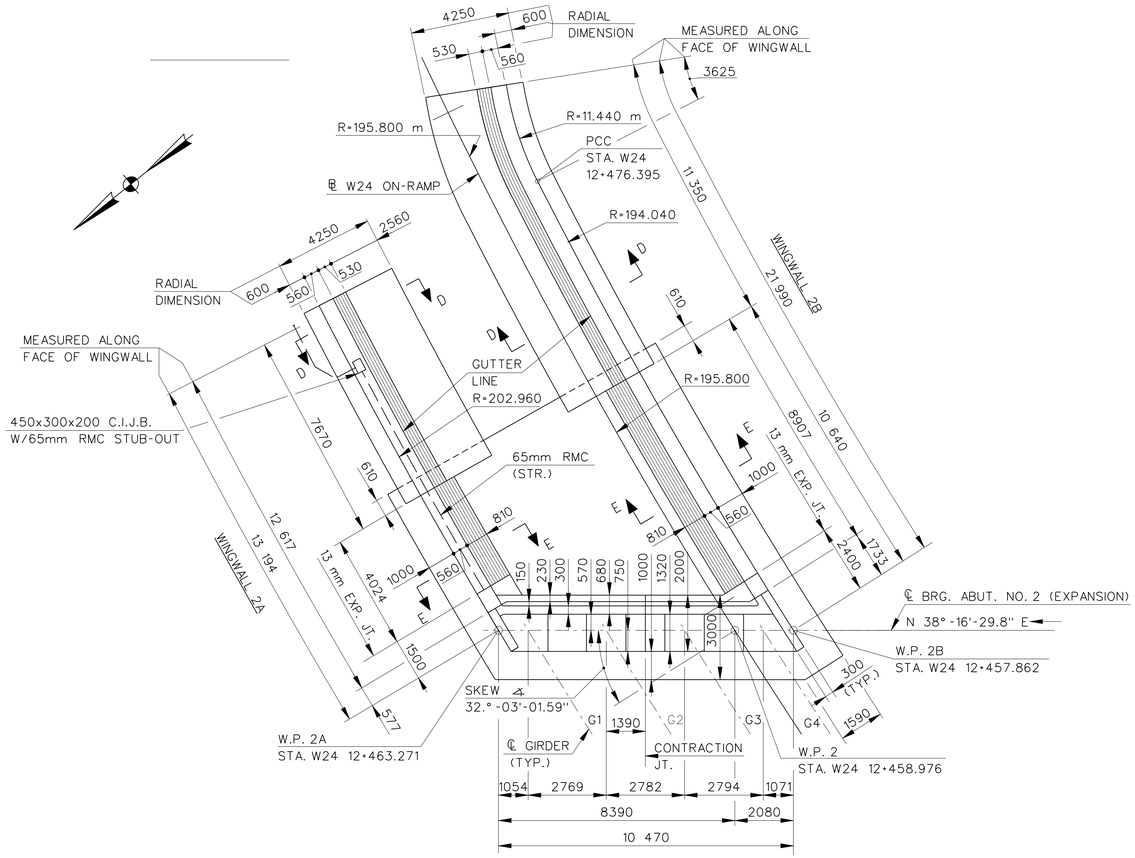
AMMANN & WHITNEY
2500 WESTCHESTER AVENUE
3RD FLOOR
HARRISON, NY

PROJECT TITLE:
RECONSTRUCTION OF I-84 WATERBURY
WB W24 ON-RAMP OVER MAD RIVER
STRUCTURE NO. 151-273-06591

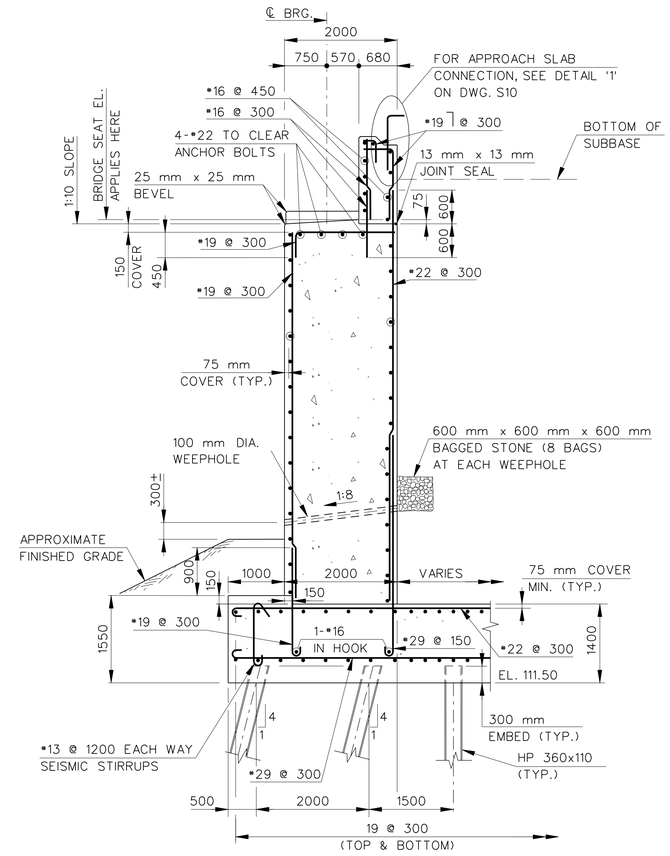
TOWN: WATERBURY

DRAWING TITLE: ABUTMENT 1 – PLAN, ELEVATION & SECTION

PROJECT NO.: 151-273
DRAWING NO.: S10
SHEET NO.: 05.08.010

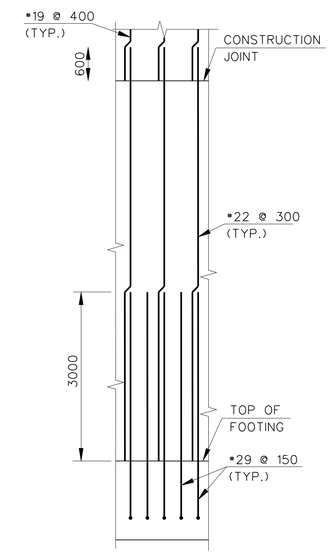


PLAN

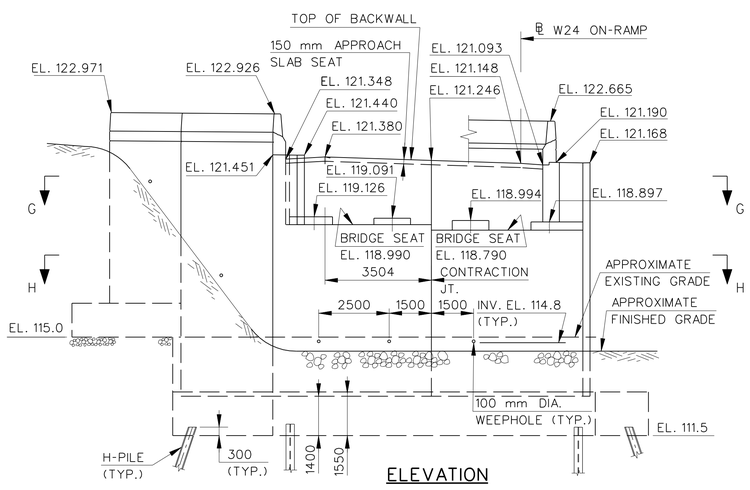


TYPICAL SECTION - ABUTMENT 2

SCALE: 1:50



REAR FACE



ELEVATION

ABUTMENT 2

SCALE: 1:100

NOTES

1. FOR WORKING POINT (W.P.) COORDINATES, SEE STR. DWG. S3.
2. FOR WINGWALL ELEVATIONS, SEE STR. DWG. S15.
3. FOR SUBSTRUCTURE DETAILS, SEE STR. DWG. S17.
4. FOR SECTIONS "D-D" AND "E-E", SEE STR. DWG. S16.
5. FOR SECTION "G-G" AND H-H, SEE STR. DWG. S13.
6. FOR MAX. DESIGN PILE LOAD, SEE 'FOOTING AND PILE PLAN' SEE STR. DWG. S9.

THE INFORMATION, INCLUDING ESTIMATED QUANTITIES OF WORK SHOWN ON THESE SHEETS IS BASED ON LIMITED INVESTIGATIONS BY THE STATE AND IS IN NO WAY WARRANTED TO INDICATE THE TRUE CONDITIONS OR THE ACTUAL QUANTITIES OR DISTRIBUTION OF QUANTITIES OF WORK WHICH WILL BE REQUIRED.

REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

DESIGNER: C. ADAMS
DRAFTER: M. MOSLEY
CHECKED BY: B. YIN
DATE CHECKED: 12/2013

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

CADD ...\Str10\FD\0273ft0011.brg
PLOTTED 4/7/2014

AMMANN & WHITNEY
2500 WESTCHESTER AVENUE
3RD FLOOR
HARRISON, NY

PROJECT TITLE: RECONSTRUCTION OF I-84 WATERBURY WB W24 ON-RAMP OVER MAD RIVER STRUCTURE NO. 151-273-06591

TOWN: WATERBURY

DRAWING TITLE: ABUTMENT 2 - PLAN, ELEVATION & SECTION

PROJECT NO.: 151-273
DRAWING NO.: S11
SHEET NO.: 05.08.011

Appendix B: Scour Computations

Based on DOT Design Discharges

- Summary Sheet
- 100-YR Contraction Scour
- 100-YR Abutment Scour
- 100-YR Contraction Scour (RS 1983 to 1962)
- 500-YR Contraction Scour
- 500-YR Abutment Scour
- 500-YR Contraction Scour (RS 1983 to 1962)

Final Design

Bridge No. 06591

Exit 24 On-Ramp, Westbound I-84 (from Harpers Ferry Road)

Computed Scour Depths using Froehlich's Abutment Scour Equation

July 2006 - revised March 2014

Abutment #1- Westerly Abutment or Left Abutment Looking Upstream

Flood Recurrence	Ave. Flow Depth Obstructed	Scour Depth (m)				
		Long-Term	Contraction	Abutment Equation	Amended Abutment	Amended Total
Q_{100}	0.00	0.3	0.25 *	N/A	0.0	0.55
Q_{500}	0.34	0.3	0.75 *	Froehlich	0.68	1.73
Overtopping	> Q_{500}					

Abutment #2- Easterly Abutment or Right Abutment Looking Upstream

Flood Recurrence	Ave. Flow Depth Obstructed	Scour Depth (m)				
		Long-Term	Contraction	Abutment Equation	Amended Abutment	Amended Total
Q_{100}	0.00	0.3	0.25 *	N/A	0.0	0.55
Q_{500}	0.40	0.3	0.75 *	Froehlich	0.47	1.52
Overtopping	> Q_{500}					

*** The computed contraction scour depth upstream of the bridge where the river channel narrows to the new trapezoidal section is 1.94 m for the 100-year, and 2.27 m for the 500-year discharges. With the proposed grade control structure, the anticipated scour depth is zero (except for the long-term scour).**

Comparison of Footing Elevations to Computed Scour Depths

Abutment No.	Depth of Footing (m)	Elevation (m)		Assumed Ground Elevation at Base of Abutment	Elevation of Scour at Abutment (m)			
					100 Year Discharge		500 Year Discharge	
		Top of Footing	Bottom of Footing		Long-Term + Contraction	Total	Long-Term + Contraction	Total
1	1.45	112.95	111.50	114.0	113.45	113.45	112.95	112.27
2	1.55	113.05	111.50	114.5	113.95	113.95	113.45	112.98

Abutment No. 1

-Top of footing below the sum of long-term channel degradation and contraction scour depths for the 100 year discharge- Design OK

-Computed total scour depth for the 100 year discharge is above the bottom of the footing, piles are not exposed by scour

-Computed total scour depth for the 500 year discharge is above the bottom of the footing, piles are not exposed by scour

Abutment No. 2

-Top of footing below the sum of long-term channel degradation and contraction scour depths for the 100 year discharge- Design OK

-Computed total scour depth for the 100 year discharge is above the bottom of the footing, piles are not exposed by scour

-Computed total scour depth for the 500 year discharge is above the bottom of the footing, piles are not exposed by scour

PROJECT NO. 151-273 **BRIDGE NO.** 06591 **UNIT:** Metric

Ref. HEC-18., May 2001 (4th ed.)

SUMMARY

Contraction Scour		Type:	**LIVE-BED**	Depth:	**0.25** m	Event:	**100-YR**
Local	**West Abut. #1**	**LEFT**	Eq.: N/A	Depth:	**N/A** m	Event:	**100-YR**
Abutment	**East Abut. #2**	**RIGHT**	Eq.: N/A	Depth:	**N/A** m	Event:	**100-YR**

CONTRACTION SCOUR

$V_c = K_u\, y^{1/6}\, D^{1/3}$ ……Eq. 5.1

= 1.48 *m/s* Critacal velocity above which bed material of size D and smaller will be transported

Ku = 6.19 m (6.19 in SI units; 11.17 in English units)

y = 2.69 m Average depth of flow upstream of the bridge

D = 0.0084 m Particle size for Vc *, m* (use D_{50})

V1 = 2.09 *m/s* The mean velocity of the flow in the main channel or overbank area upstream of the brige opening

Vc < V1 ***Thus, LIVE-BED CONTRACTION SCOUR***

Live-Bed Contraction Scour ==========

$Y_2/Y_1 = (Q_2/Q_1)^{6/7}\,(W_1/W_2)^{k_1}$ = 1.00 ……Eq. 5.2

$Y_s = Y_2 - Y_o$ m ……Eq. 5.3

= 0.25 m Average contraction scour depth

Y_1 = 2.69 m Average depth in the upstream main channel

Y_2 = 2.69 m Average depth in the contracted section

Y_o = 2.44 m Existing depth in the contracted section before scour

Q_1 = 176.98 m3/s Flow in the upstream channel transporting sediment

Q_2 = 176.98 m3/s Flow in the contracted channel

W_1 = 12.00 m Bottom width of the upstream main channel that is transporting bed material

W_2 = 12.00 m Bottom width of the main channel in the contracted section less pier width

k_1 = 0.64 Exponent determined below (V^*/ω = 0.73)

V^* = 0.3155 $=(T_o/\rho)^{1/2}$ or $(gY1\ S1)^{1/2}$, shear velocity in the upstream section , m/s

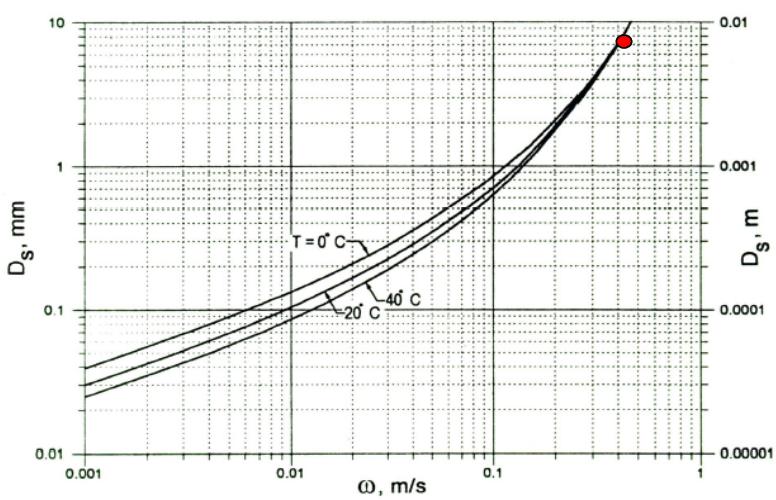
ω = 0.43 m/s Fall velocity of bed material based on the D_{50} (Figure 5.8)

g = 9.81 m/s^2 Acceleration of gravity

S1 = 0.002329 m/m Slope of energy gradeline of main channel

T_o = 99.51 Pa (N/m^2) Shear stess on the bed

ρ = 1000 kg/m^3 Density of water



V/ω*	*k1*	*Mode of Bed Material Transport*
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

Figure 5.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Clear-Water Contraction Scour ==========

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2} \right]^{3/7}$$ .....Eq. 5.4

$y_s = y_2 - y_o$ **m** .....Eq. 5.5

=	**N/A**	**m**	Average contraction scour depth **LIVE-BED controls. Ignore this procedure**
y_2 =	7.60	m	Average equilibrium depth in the contracted section after contraction scour
y_o =	2.44	m	Average existing depth in the contracted section
Q =	176.98	m3/s	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width V
W =	12.00	m	Bottom width of the contracted section less pier widths
K_u =	0.0250		(0.025 in SI units; 0.0077 in English units)
D_m =	0.0105	m	Diameter of the smallest nontransportable particle in the bed material (1.25 D_{50}) in th contacted setion
D_{50} =	0.0084	m	Median diameter of bed material

Because D_{50} is not the largest particle in the bed material, the scoured section can be slightly armored. Therefore, the D_m is assumed to be 1.25 D_{50}. For stratified bed material the depth of scour can be determined by using the clear-water scour equation sequentially with successive D_m of the bed material layers.

Data Source

Eq. 5.1			From:	RS
y =	2.69	m	C	1962
V1 =	2.09	m	C	1938.5 BR U

Eq. 5.2 & 5.3				
Y1 =	2.69	m	C	1962
Yo =	2.44	m	C	1938.5 BR U
Q1 =	176.98	m3/s	C	1962
Q2 =	176.98	m3/s	C	1938.5 BR U
W1 =	31.45	m	C	1962
or	12	m (manual)		
W2 =	25.1	m	C	1938.5 BR U
or	12	m (manual)		
S1 =	0.002329	m/m	C	1962
To =	99.51	Pa (N/m^2)	C	1938.5 BR U
P2 =	0	m (pier width)		

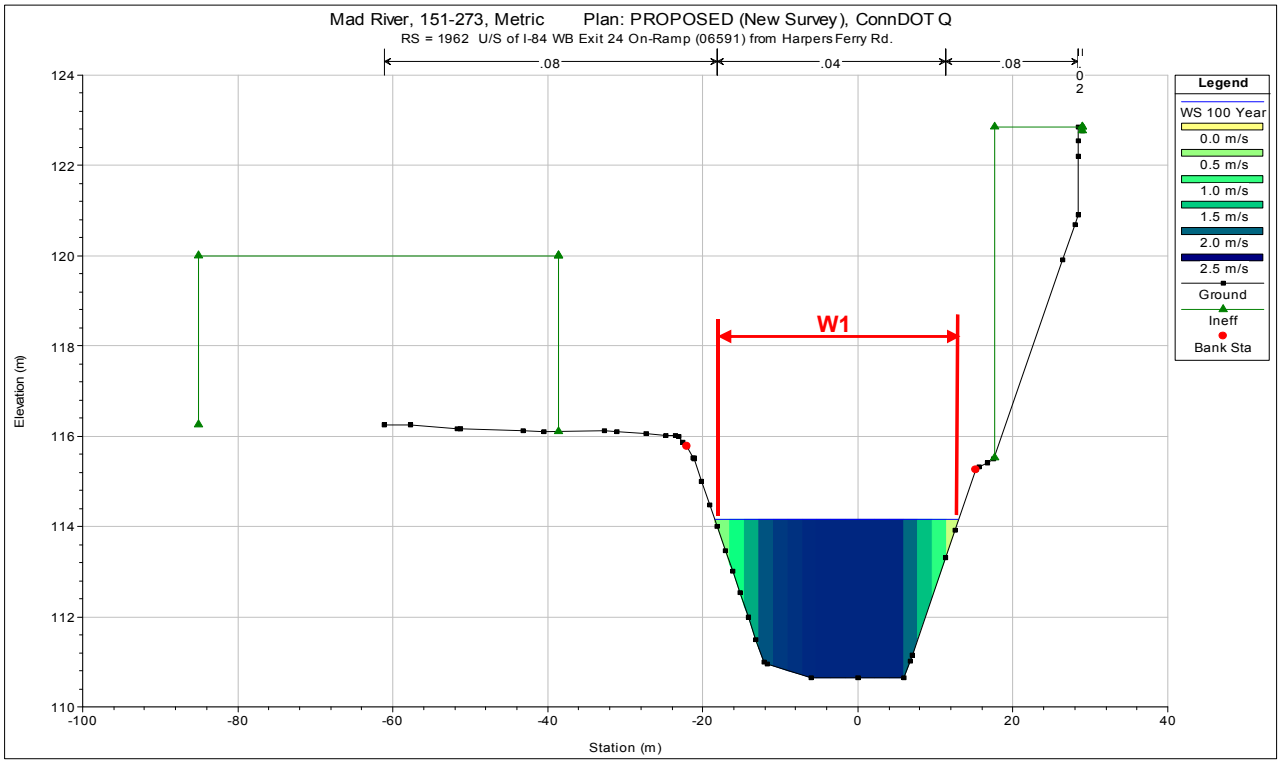
Eq. 5.4 & 5.5				
Q =	176.98	m3/s	C	1938.5

Legends:

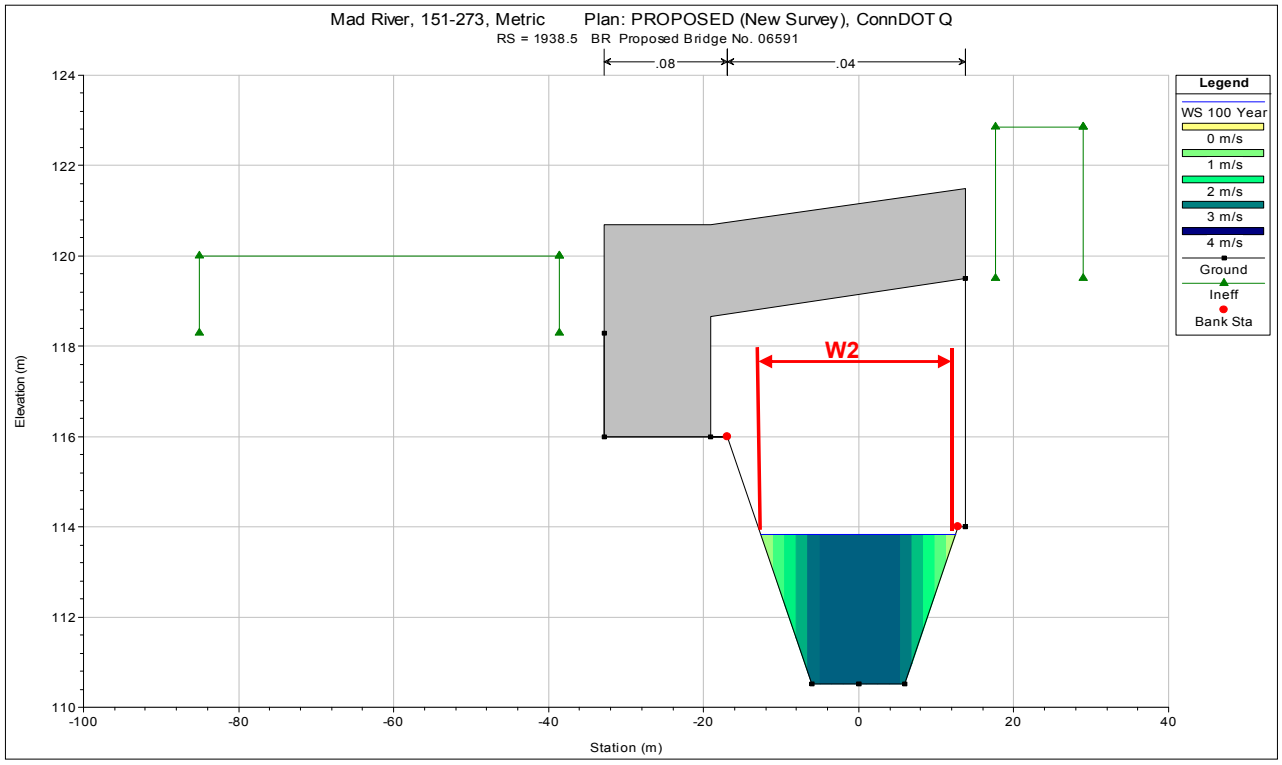
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

Cross Sections used for Constraction Scour Computations

UPSTREAM SECTION **1962**



CONTRACTED SECTION **1938.5 BR U**



UPSTREAM CHANNEL SECTION

River Station 1962 Event: 100-YR

HEC-RAS CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 100 Year

			Left OB	Channel	Right OB	Total
E.G. Elev (m)	114.37	Element				
Vel Head (m)	0.22	Wt. n-Val.		0.043		
W.S. Elev (m)	114.15	Reach Len. (m)	17.4	17.4	17.4	
Crit W.S. (m)	112.7	Flow Area (m2)		84.65		
E.G. Slope (m/m)	0.002329	Area (m2)		84.65		84.65
Q Total (m3/s)	176.98	Flow (m3/s)		176.98		
Top Width (m)	31.45	Top Width (m)		31.45		
Vel Total (m/s)	2.09	Avg. Vel. (m/s)		2.09		
Max Chl Dpth (m)	3.5	Hydr. Depth (m)		2.69		2.69
Conv. Total (m3/s)	3667.5	Conv. (m3/s)		3667.5		
Length Wtd. (m)	17.4	Wetted Per. (m)		33.02		
Min Ch El (m)	110.65	Shear (N/m2)		58.53		
Alpha	1	Stream Power (N/m s)	1385.59	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	9.82	68.03	4.23	
C & E Loss (m)	0.06	Cum SA (1000 m2)	23.49	28.8	6.51	

		Flow dis.	*manual*
Left WS Sta.			-18.46
Left Flood Sta.	(data)		-21.08
Left Main Channel		-7.17	
Right Main Channel		7.76	
Right Flood Sta.	(data)		12.87
Right WS Sta.			12.99
L' (left)	13.91	L (left)	11.29
L' (Right)	5.11	L (Right)	5.23

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1	
LEFT		51.33	26.4			51.3121
Main	14.93	116.89	51.42	3.44	2.27	116.818
Right		8.73	6.84			8.7107

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 100 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)	A x V
1	Chan	-20.22	-18.36	0	0	0.11	0	0.02	0.04	0.5	0.02	0
2	Chan	-18.36	-16.49	0.6	0.96	2.09	0.34	0.52	0.63	10.52	6.58	0.6048
3	Chan	-16.49	-14.63	3.21	2.7	2.08	1.82	1.45	1.19	29.55	35.21	3.213
4	Chan	-14.63	-12.76	7.35	4.43	2.09	4.15	2.38	1.66	48.53	80.49	7.3538
5	Chan	-12.76	-10.9	12.25	5.85	1.94	6.92	3.14	2.09	68.8	144.03	12.2265
6	Chan	-10.9	-9.03	13.62	6.14	1.87	7.7	3.29	2.22	75.07	166.55	13.6308
7	Chan	-9.03	-7.17	14.3	6.32	1.87	8.08	3.39	2.26	77.28	174.84	14.2832
8	Chan	-7.17	-5.3	14.95	6.49	1.87	8.45	3.48	2.3	79.39	182.84	14.927
9	Chan	-5.3	-3.44	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
10	Chan	-3.44	-1.57	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
11	Chan	-1.57	0.3	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
12	Chan	0.3	2.16	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
13	Chan	2.16	4.03	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
14	Chan	4.03	5.89	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
15	Chan	5.89	7.76	11.4	5.75	2.07	6.44	3.08	1.98	63.37	125.59	11.385
16	Chan	7.76	9.62	6.23	4.01	2.09	3.52	2.15	1.55	43.92	68.16	6.2155
17	Chan	9.62	11.49	2.36	2.27	2.09	1.34	1.22	1.04	24.83	25.87	2.3608
18	Chan	11.49	13.35	0.14	0.56	1.68	0.08	0.37	0.24	7.65	1.85	0.1344
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CONTRACTED CHANNEL SECTION

River Station 1938.5 BR U

CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 100 Year

E.G. Elev (m)	114.26	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.43	Wt. n-Val.		0.04		
W.S. Elev (m)	113.83	Reach Len. (m)	12.8	12.8	12.8	
Crit W.S. (m)	112.97	Flow Area (m2)		61.19		
E.G. Slope (m/m)	0.004422	Area (m2)		61.19		61.19
Q Total (m3/s)	176.98	Flow (m3/s)		176.98		
Top Width (m)	25.1	Top Width (m)		25.1		
Vel Total (m/s)	2.89	Avg. Vel. (m/s)		2.89		
Max Chl Dpth (m)	3.3	Hydr. Depth (m)		2.44		2.44
Conv. Total (m3/s)	2661.6	Conv. (m3/s)		2661.6		
Length Wtd. (m)	12.8	Wetted Per. (m)		26.66		
Min Ch El (m)	110.53	Shear (N/m2)		99.51		
Alpha	1	Stream Power (N/m s)	658.33	0	0	
Frctn Loss (m)	0.06	Cum Volume (1000 m3)	9.82	66.76	4.23	
C & E Loss (m)	0.01	Cum SA (1000 m2)	23.49	28.31	6.51	

		Flow dis.	*manual*
Left WS Sta.		-13.95	-12.59
Left Flood Sta.			-12.59
Left Main Channel		-8	
Right Main Channel		6.89	12.5
Right Flood Sta.			12.5
Right WS Sta.		12.84	12.5
L' (left)	4.59	L (left)	4.59
L' (Right)	5.61	L (Right)	5.61

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1	
LEFT		9.22	5.28			9.2379
Main	14.89	151.56	47.91	3.22	3.16	151.583
Right		16.21	8.01			16.21

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 100 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)	A x V
1	Chan	-13.95	-12.46	0	0	0.14	0	0.03	0.14	1.24	0.17	0
2	Chan	-12.46	-10.98	0.51	0.65	1.66	0.29	0.44	0.78	16.92	13.25	0.507
3	Chan	-10.98	-9.49	2.67	1.76	1.66	1.51	1.18	1.52	45.81	69.67	2.6752
4	Chan	-9.49	-8	6.04	2.87	1.66	3.41	1.93	2.11	74.69	157.38	6.0557
5	Chan	-8	-6.51	10.42	3.98	1.66	5.89	2.67	2.62	103.57	271.39	10.4276
6	Chan	-6.51	-5.02	15.2	4.85	1.55	8.59	3.26	3.14	135.65	425.47	15.229
7	Chan	-5.02	-3.53	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
8	Chan	-3.53	-2.05	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
9	Chan	-2.05	-0.56	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
10	Chan	-0.56	0.93	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
11	Chan	0.93	2.42	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
12	Chan	2.42	3.91	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
13	Chan	3.91	5.4	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
14	Chan	5.4	6.89	14.22	4.71	1.6	8.03	3.17	3.02	128	386.27	14.2242
15	Chan	6.89	8.37	9.14	3.68	1.67	5.16	2.47	2.48	95.59	237.43	9.1264
16	Chan	8.37	9.86	4.98	2.56	1.67	2.81	1.72	1.95	66.39	129.32	4.992
17	Chan	9.86	11.35	1.89	1.43	1.67	1.07	0.96	1.32	37.19	49.22	1.8876
18	Chan	11.35	12.84	0.2	0.34	1.29	0.11	0.29	0.6	11.29	6.75	0.204
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LIVE SCOUR AT ABUTMENTS

Froehlich's Live-Bed Abutment Scour Equation — *LEFT* — *RIGHT* — ==========

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 1 =$ **N/A** **N/A** .....Eq. 7.1

Amended Local Scour Equation

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 0.05 =$ **N/A** **N/A** .....CT DOT DM Pg 9B-2

	LEFT	*RIGHT*		
Ys =	**N/A**	**N/A**	**m**	Scour depth <== using Amended equation
K_1 =	1.00	1.00		Coeffcient for abutment shape (see Table 7.1 and Figrue 7.6)
K_2 =	1.08	0.96		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
θ =	160	66		
				θ < 90 degrees if embankment points downstream
				θ > 90 degrees if embankment points upstream
				(see Figure 7.5 for definition of θ)
L' =	0.00	0.00	m	Length of active flow obstructed by the embankment (see Figure 7.4)
Ae =	0.00	0.00	m^2	Flow area of the approach cross section obstructed by the embankment
Fr =	N/A	N/A		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment
Ve =	N/A	N/A	m/s	Qe/Ae
Qe =	0	0	m^3/s	Flow obstructed by the abutment and approach embankment
Ya =	N/A	N/A	m	Ae/L, Average depth of flow on the floodplain
L =	0	0	m	Length of embankment projected normal to the flow

Table 7.1. Abutment Shape Coefficients.

Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

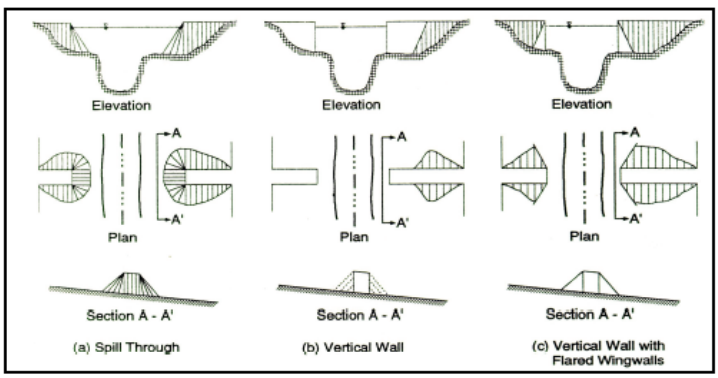


Figure 7.6. Abutment shape.

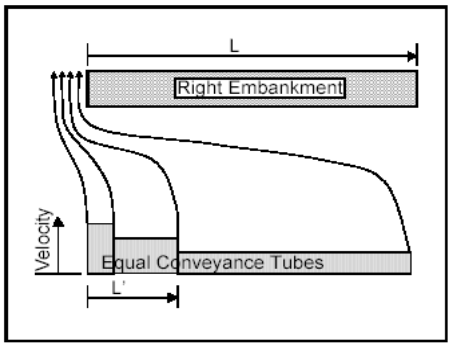


Figure 7.4. Determination of length of embankment blocking live flow for abutment scour estimation.

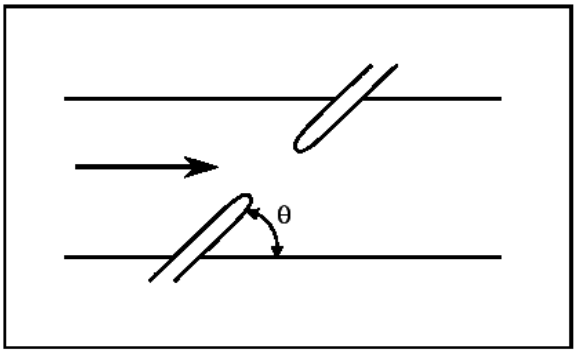


Figure 7.5. Orientation of embankment angle, θ, to the flow.

HIRE Live-Bed Abutment Scour Equation ==========

		LEFT	RIGHT	
Applicability check:	L/Y_1 =	N/A	N/A	*Use HIRE Eq. only if L/Y_1 > 25*
Y_s/Y_1 = 4 $Fr^{0.33}$ K_1/0.55 K_2 =		**N/A**	**N/A**	.....Eq. 7.1

	LEFT	RIGHT		
Ys =	**N/A**	**N/A**	**m**	Scour depth (N/A if L/Y_1 < 25)
K_1 =	1.00	1.00		Coeffcient for abutment shape (see Table 7.1 on RIGHT)
K_2 =	1.08	0.96		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
Y_1 =	N/A	N/A	m	Depth of flow at the abutment on the overbank or in the main channel,
Fr =	N/A	N/A		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment

Data Source

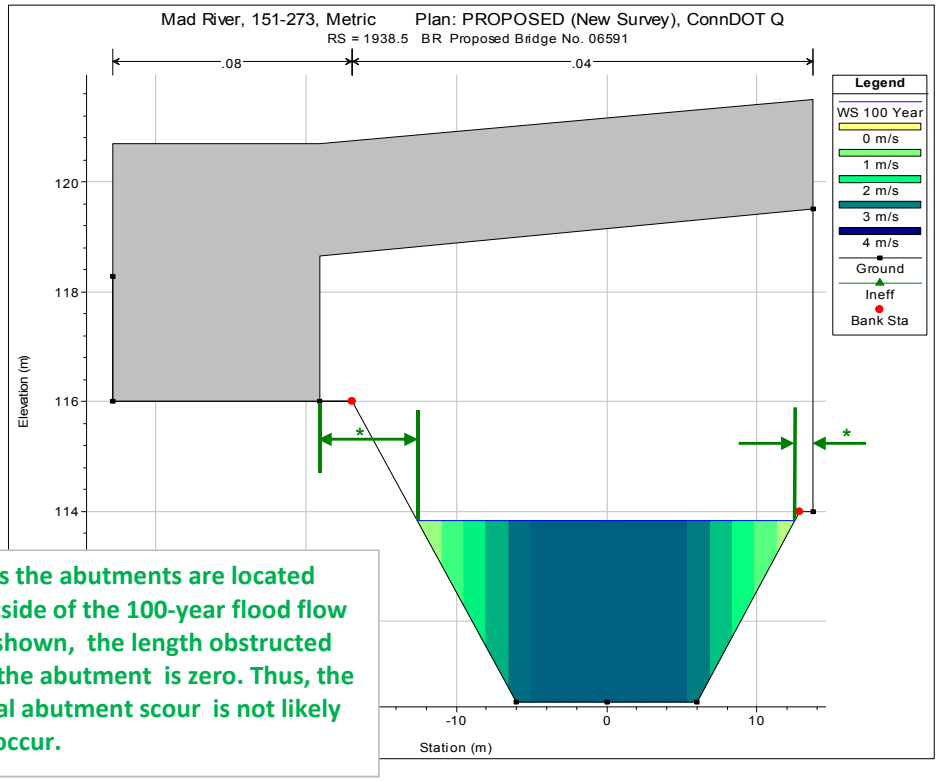
Eq. 7.1			From:	RS
LT			UF	
	L' =	0 m	D	1938.5 BR U
	Ae =	0 m2	D	1938.5 BR U
	Qe =	0 m3/s	D	1938.5 BR U
	L =	0 m	D	1938.5 BR U
RT			UC	
	L' =	0 m	D	1962
	Ae =	0 m2	D	1962
	Qe =	0 m3/s	D	1962
	L =	0 m	D	1962

Legends:

UC	from an upstream Cross Section output (approach section)
UF	from Bridge Upstream Face - Cross Section output (BR U); or Bridge Downstream Face (BR D) - this is seldom used
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

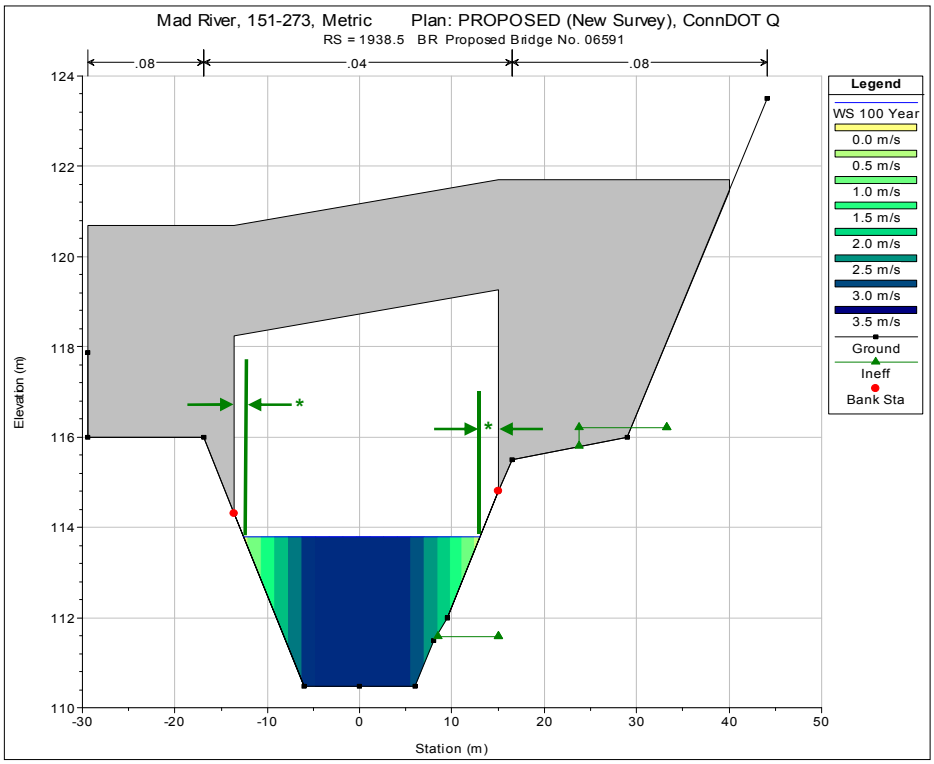
Cross Sections Used for Local Abutment Scour Computations

BRIDGE SECTION **1938.5 BR U**



*** As the abutments are located outside of the 100-year flood flow as shown, the length obstructed by the abutment is zero. Thus, the local abutment scour is not likely to occur.**

BRIDGE SECTION **1938.5 BR D**



UPSTREAM APPROACH CHANNEL SECTION

River Station 1962 Event: 100-YR

CROSS SECTION OUTPUT ***Use the same data as in the contraction scour computation?*** No

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 100 Year

E.G. Elev (m)	114.37	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.22	Wt. n-Val.		0.043		
W.S. Elev (m)	114.15	Reach Len. (m)	17.4	17.4	17.4	
Crit W.S. (m)	112.7	Flow Area (m2)		84.65		
E.G. Slope (m/m)	0.002329	Area (m2)		84.65		84.65
Q Total (m3/s)	176.98	Flow (m3/s)		176.98		
Top Width (m)	31.45	Top Width (m)		31.45		
Vel Total (m/s)	2.09	Avg. Vel. (m/s)		2.09		
Max Chl Dpth (m)	3.5	Hydr. Depth (m)		2.69		2.69
Conv. Total (m3/s)	3667.5	Conv. (m3/s)		3667.5		
Length Wtd. (m)	17.4	Wetted Per. (m)		33.02		
Min Ch El (m)	110.65	Shear (N/m2)		58.53		
Alpha	1	Stream Power (N/m s)	1385.59	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	9.82	68.03	4.23	
C & E Loss (m)	0.06	Cum SA (1000 m2)	23.49	28.8	6.51	

		Flow dis.	*manual*
Left WS Sta.			-18.46
Left Flood Sta.		(data)	-18.46
Left Main Channel		-18.36	
Right Main Channel		12.99	
Right Flood Sta.		(data)	12.99
Right WS Sta.			12.99
L' (left)	0.1	L (left)	0.1
L' (Right)	0	L (Right)	0

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1	
LEFT		0	0			0
Main	31.35	176.95	84.66	2.70	2.09	176.8406
Right		0	0			0

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 100 Year

Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)	A x V
1 Chan	-20.22	-18.36	0	0	0.11	0	0.02	0.04	0.5	0.02	0
2 Chan	-18.36	-16.49	0.6	0.96	2.09	0.34	0.52	0.63	10.52	6.58	0.6048
3 Chan	-16.49	-14.63	3.21	2.7	2.08	1.82	1.45	1.19	29.55	35.21	3.213
4 Chan	-14.63	-12.76	7.35	4.43	2.09	4.15	2.38	1.66	48.53	80.49	7.3538
5 Chan	-12.76	-10.9	12.25	5.85	1.94	6.92	3.14	2.09	68.8	144.03	12.2265
6 Chan	-10.9	-9.03	13.62	6.14	1.87	7.7	3.29	2.22	75.07	166.55	13.6308
7 Chan	-9.03	-7.17	14.3	6.32	1.87	8.08	3.39	2.26	77.28	174.84	14.2832
8 Chan	-7.17	-5.3	14.95	6.49	1.87	8.45	3.48	2.3	79.39	182.84	14.927
9 Chan	-5.3	-3.44	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
10 Chan	-3.44	-1.57	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
11 Chan	-1.57	0.3	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
12 Chan	0.3	2.16	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
13 Chan	2.16	4.03	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
14 Chan	4.03	5.89	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77	15.0843
15 Chan	5.89	7.76	11.4	5.75	2.07	6.44	3.08	1.98	63.37	125.59	11.385
16 Chan	7.76	9.62	6.23	4.01	2.09	3.52	2.15	1.55	43.92	68.16	6.2155
17 Chan	9.62	11.49	2.36	2.27	2.09	1.34	1.22	1.04	24.83	25.87	2.3608
18 Chan	11.49	13.35	0.14	0.56	1.68	0.08	0.37	0.24	7.65	1.85	0.1344
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BRIDGE SECTION

River Station 1938.5 BR U

CROSS SECTION OUTPUT ***Use the same data as in the contraction scour computation?*** No

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 100 Year

E.G. Elev (m)	114.26	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.43	Wt. n-Val.		0.04		
W.S. Elev (m)	113.83	Reach Len. (m)	12.8	12.8	12.8	
Crit W.S. (m)	112.97	Flow Area (m2)		61.19		
E.G. Slope (m/m)	0.004422	Area (m2)		61.19		61.19
Q Total (m3/s)	176.98	Flow (m3/s)		176.98		
Top Width (m)	25.1	Top Width (m)		25.1		
Vel Total (m/s)	2.89	Avg. Vel. (m/s)		2.89		
Max Chl Dpth (m)	3.3	Hydr. Depth (m)		2.44		2.44
Conv. Total (m3/s)	2661.6	Conv. (m3/s)		2661.6		
Length Wtd. (m)	12.8	Wetted Per. (m)		26.66		
Min Ch El (m)	110.53	Shear (N/m2)		99.51		
Alpha	1	Stream Power (N/m s)	658.33	0	0	
Frctn Loss (m)	0.06	Cum Volume (1000 m3)	9.82	66.76	4.23	
C & E Loss (m)	0.01	Cum SA (1000 m2)	23.49	28.31	6.51	

	Flow dis.	*manual*
Left WS Sta.	-13.95	-12.59
Left Flood Sta.	-12.59	
Left Main Channel	-12.59	
Right Main Channel	12.5	
Right Flood Sta.		12.5
Right WS Sta.		12.5
L' (left) 0	L (left)	0
L' (Right) 0	L (Right)	0

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1	
LEFT		0	0			0
Main	25.09	176.99	61.2	2.44	2.89	177.0312
Right						

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 100 Year

Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)	A x V
1 Chan	-13.95	-12.46	0	0	0.14	0	0.03	0.14	1.24	0.17	0
2 Chan	-12.46	-10.98	0.51	0.65	1.66	0.29	0.44	0.78	16.92	13.25	0.507
3 Chan	-10.98	-9.49	2.67	1.76	1.66	1.51	1.18	1.52	45.81	69.67	2.6752
4 Chan	-9.49	-8	6.04	2.87	1.66	3.41	1.93	2.11	74.69	157.38	6.0557
5 Chan	-8	-6.51	10.42	3.98	1.66	5.89	2.67	2.62	103.57	271.39	10.4276
6 Chan	-6.51	-5.02	15.2	4.85	1.55	8.59	3.26	3.14	135.65	425.47	15.229
7 Chan	-5.02	-3.53	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
8 Chan	-3.53	-2.05	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
9 Chan	-2.05	-0.56	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
10 Chan	-0.56	0.93	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
11 Chan	0.93	2.42	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
12 Chan	2.42	3.91	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
13 Chan	3.91	5.4	15.96	4.91	1.49	9.02	3.3	3.25	143.05	464.86	15.9575
14 Chan	5.4	6.89	14.22	4.71	1.6	8.03	3.17	3.02	128	386.27	14.2242
15 Chan	6.89	8.37	9.14	3.68	1.67	5.16	2.47	2.48	95.59	237.43	9.1264
16 Chan	8.37	9.86	4.98	2.56	1.67	2.81	1.72	1.95	66.39	129.32	4.992
17 Chan	9.86	11.35	1.89	1.43	1.67	1.07	0.96	1.32	37.19	49.22	1.8876
18 Chan	11.35	12.84	0.2	0.34	1.29	0.11	0.29	0.6	11.29	6.75	0.204
19											
20											
21											
22											
23											
24											

BRIDGE OUTPUT

River Station 1938.5

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 Profile: 100 Year

E.G. US. (m)	114.37	Element	Inside BR US	Inside BR DS
W.S. US. (m)	114.15	E.G. Elev (m)	114.26	114.19
Q Total (m3/s)	176.98	W.S. Elev (m)	113.83	113.78
Q Bridge (m3/s)	176.98	Crit W.S. (m)	112.97	112.91
Q Weir (m3/s)		Max Chl Dpth (m)	3.3	3.3
Weir Sta Lft (m)		Vel Total (m/s)	2.89	2.85
Weir Sta Rgt (m)		Flow Area (m2)	61.19	62.13
Weir Submerg		Froude # Chl	0.59	0.58
Weir Max Depth (m)		Specif Force (m3)	141.21	141.43
Min El Weir Flow (m)	120.7	Hydr Depth (m)	2.44	2.43
Min El Prs (m)	119.5	W.P. Total (m)	26.66	27.09
Delta EG (m)	0.36	Conv. Total (m3/s)	2661.6	2701
Delta WS (m)	0.4	Top Width (m)	25.1	25.56
BR Open Area (m2)	203.36	Frctn Loss (m)	0.06	0.11
BR Open Vel (m/s)	2.89	C & E Loss (m)	0.01	0.07
Coef of Q		Shear Total (N/m2)	99.51	96.55
Br Sel Method	Energy only	Power Total (N/m s)	-1572.79	-1409.04

PROJECT NO. 151-273 **BRIDGE NO.** 06591 **UNIT:** Metric

Ref. HEC-18., May 2001 (4th ed.)

SUMMARY

Contraction Scour	Type: **LIVE-BED**	Depth: **1.94** m	Event: **100-YR**

CONTRACTION SCOUR (RS 1+962)

$V_c = K_u y^{1/6} D^{1/3}$ ……Eq. 5.1

= 1.54 *m/s* Critacal velocity above which bed material of size D and smaller will be transported

Ku = 6.19 m (6.19 in SI units; 11.17 in English units)

y = 3.40 m Average depth of flow upstream of the bridge

D = 0.0084 m Particle size for Vc *, m* (use D_{50})

V1 = 2.25 *m/s* The mean velocity of the flow in the main channel or overbank area upstream of the brige opening

Vc < V1 ***Thus, LIVE-BED CONTRACTION SCOUR***

Live-Bed Contraction Scour ==========

$Y_2/Y_1 = (Q_2/Q_1)^{6/7} (W_1/W_2)^{k_1}$ = 1.57 ……Eq. 5.2

$Y_s = Y_2 - Y_o$ m ……Eq. 5.3

= 1.94 m Average contraction scour depth

Y_1 = 3.40 m Average depth in the upstream main channel

Y_2 = 5.33 m Average depth in the contracted section

Y_o = 3.40 m Existing depth in the contracted section before scour

Q_1 = 77.14 m3/s Flow in the upstream channel transporting sediment

Q_2 = 157.06 m3/s Flow in the contracted channel

W_1 = 16.00 m Bottom width of the upstream main channel that is transporting bed material

W_2 = 20.52 m Bottom width of the main channel in the contracted section less pier width

k_1 = 0.64 Exponent determined below (V^*/ω = 0.56)

V^* = 0.2419 $=(T_o/\rho)^{1/2}$ or $(gY1\ S1)^{1/2}$, shear velocity in the upstream section , m/s

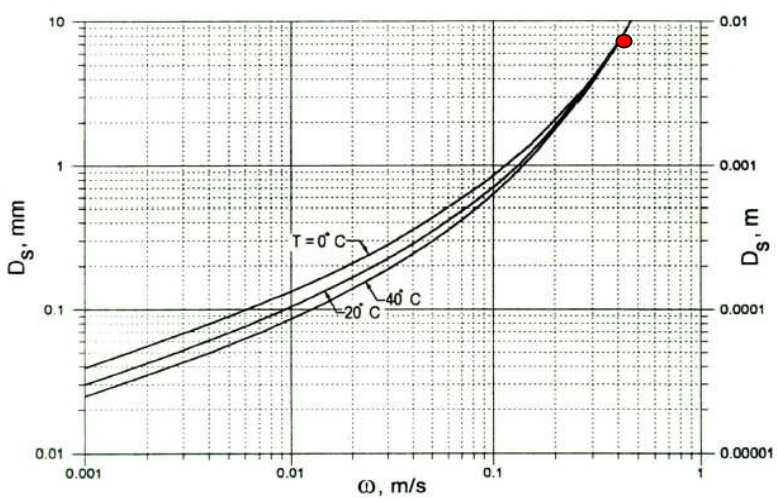
ω = 0.43 m/s Fall velocity of bed material based on the D_{50} (Figure 5.8)

g = 9.81 m/s^2 Acceleration of gravity

S1 = 0.000652 m/m Slope of energy gradeline of main channel

T_o = 58.53 Pa (N/m^2) Shear stess on the bed

ρ = 1000 kg/m^3 Density of water



V^*/ω	k1	*Mode of Bed Material Transport*
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

Figure 5.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Clear-Water Contraction Scour ==========

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2}\right]^{3/7}$$ .....Eq. 5.4

$$y_s = y_2 - y_o$$ **m** .....Eq. 5.5

=	**N/A**	**m**	Average contraction scour depth **LIVE-BED controls. Ignore this procedure**
y_2 =	4.80	m	Average equilibrium depth in the contracted section after contraction scour
y_o =	3.40	m	Average existing depth in the contracted section
Q =	176.98	m3/s	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W
W =	20.52	m	Bottom width of the contracted section less pier widths
K_u =	0.0250		(0.025 in SI units; 0.0077 in English units)
D_m =	0.0105	m	Diameter of the smallest nontransportable particle in the bed material (1.25 D_{50}) in th contacted setion
D_{50} =	0.0084	m	Median diameter of bed material

Because D_{50} is not the largest particle in the bed material, the scoured section can be slightly armored. Therefore, the D_m is assumed to be 1.25 D_{50}. For stratified bed material the depth of scour can be determined by using the clear-water scour equation sequentially with successive D_m of the bed material layers.

Data Source

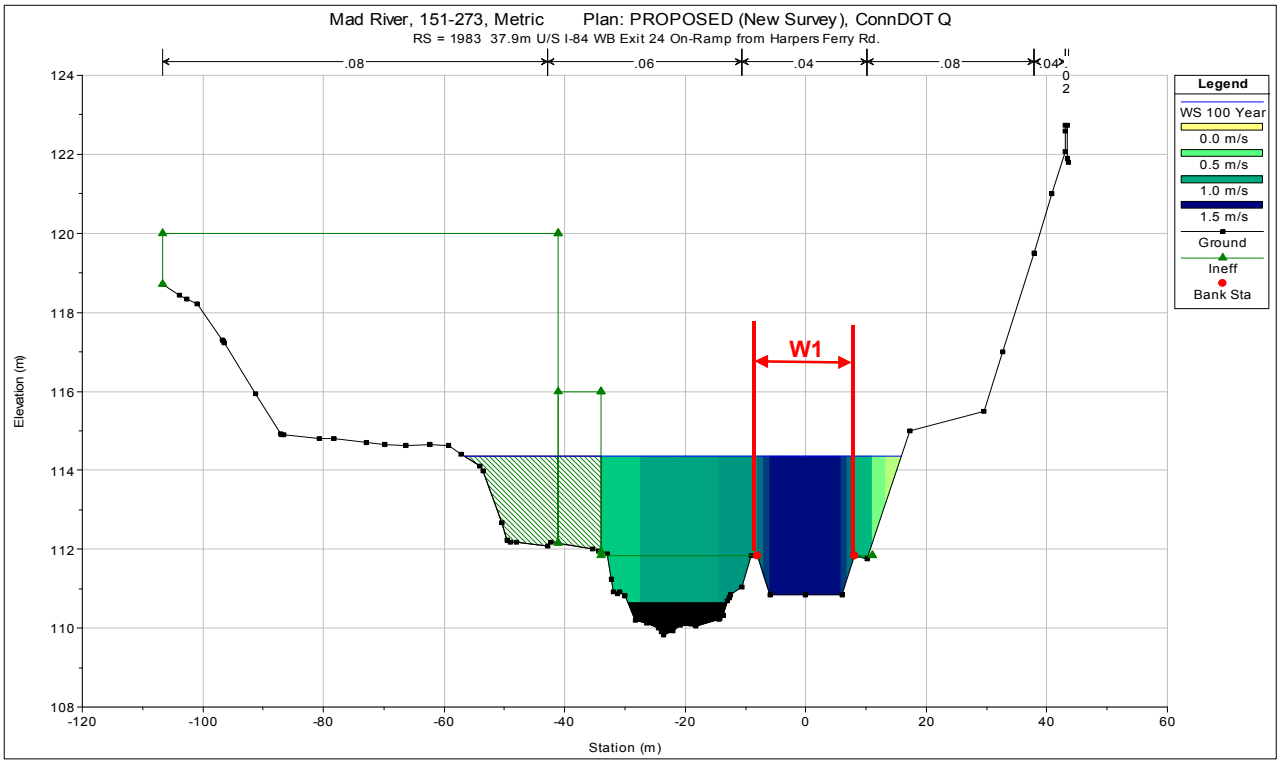
			From:	RS
Eq. 5.1				
y =	3.40	m	C	1983
V1 =	2.25	m	D	1962
Eq. 5.2 & 5.3				
Y1 =	3.40	m	C	1983
Yo =	3.40	m	D	1962
Q1 =	77.14	m3/s	C	1983
Q2 =	157.06	m3/s	D	1962
W1 =	16	m	C	1983
or	(n/a)	m (manual)		
W2 =	20.52	m	D	1962
or	(n/a)	m (manual)		
S1 =	0.000652	m/m	C	1983
To =	58.53	Pa (N/m^2)	C	1962
P2 =	0	m (pier width)		
Eq. 5.4 & 5.5				
Q =	176.98	m3/s	M	

Legends:

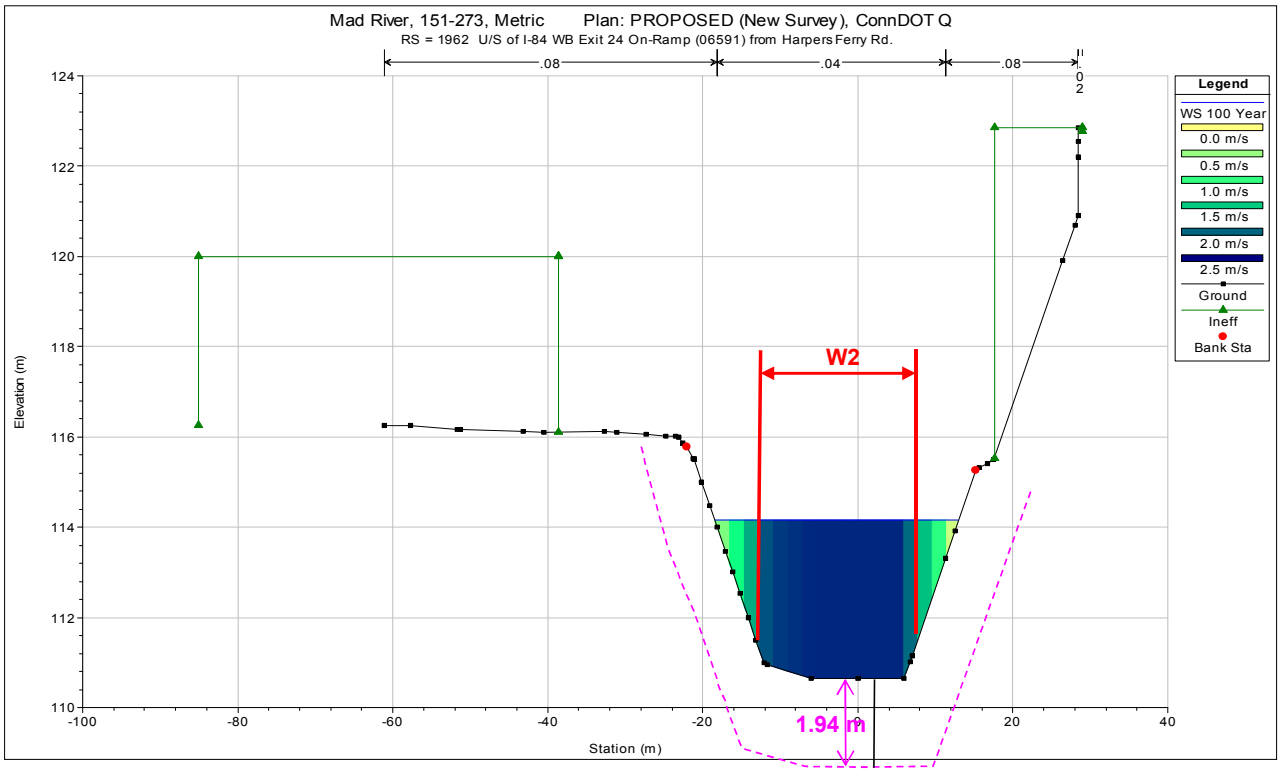
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

Cross Sections used for Constraction Scour Computations

UPSTREAM SECTION 1983



CONTRACTED SECTION 1962



UPSTREAM CHANNEL SECTION

River Station 1983 Event: 100-YR

HEC-RAS CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1983 Profile: 100 Year

E.G. Elev (m)	114.44	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.07	Wt. n-Val.	0.058	0.04	0.052	
W.S. Elev (m)	114.37	Reach Len. (m)	12	10.3	8.5	
Crit W.S. (m)	112.16	Flow Area (m2)	90.67	54.45	12.83	
E.G. Slope (m/m)	0.000652	Area (m2)	131.35	54.45	12.83	198.63
Q Total (m3/s)	176.98	Flow (m3/s)	90.72	77.14	9.11	
Top Width (m)	72.5	Top Width (m)	48.69	16	7.81	
Vel Total (m/s)	1.12	Avg. Vel. (m/s)	1	1.42	0.71	
Max Chl Dpth (m)	3.72	Hydr. Depth (m)	3.5	3.4	1.64	2.74
Conv. Total (m3/s)	6929	Conv. (m3/s)	3551.9	3020.2	356.8	
Length Wtd. (m)	11.01	Wetted Per. (m)	26.56	16.47	8.38	
Min Ch El (m)	110.84	Shear (N/m2)	21.84	21.15	9.8	
Alpha	1.13	Stream Power (N/m s)	2083.64	0	0	
Frctn Loss (m)	0.01	Cum Volume (1000 m3)	11.62	69.31	4.35	
C & E Loss (m)	0.02	Cum SA (1000 m2)	24.26	29.21	6.59	

	Flow dis.	*manual*
Left WS Sta.	-60.72	-56.69
Left Convy Sta.	-33.9	
Left Main Channel	-8	
Right Main Channel	8	
Right Convy Sta.	15.65	
Right WS Sta.		15.81
L' (left) 25.9	L (left)	48.69
L' (Right) 7.65	L (Right)	7.81

HEC-RAS FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		90.71	131.34		
Main	16	77.17	54.42	3.40	1.42
Right		9.12	12.83		

Plan: PR_DOT Mad River Reach 1 RS: 1983 Profile: 100 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	-60.72	-54.14	0	0.3	2.56	0	0.12	0	0.75	0
2	LOB	-54.14	-47.57	0	9.34	6.97	0	1.42	0	8.57	0
3	LOB	-47.57	-41	0	14.62	6.58	0	2.22	0	14.21	0
4	LOB	-41	-33.9	0	16.42	7.1	0	2.31	0	14.79	0
5	LOB	-33.9	-27.42	19.51	21.53	6.9	11.03	3.33	0.91	19.95	18.08
6	LOB	-27.42	-20.95	24.52	24.07	6.47	13.86	3.72	1.02	23.78	24.23
7	LOB	-20.95	-14.48	24.52	24.07	6.47	13.86	3.72	1.02	23.78	24.23
8	LOB	-14.48	-8	22.16	20.99	6.71	12.52	3.24	1.06	20.02	21.14
9	Chan	-8	-6.93	3.48	2.98	1.19	1.97	2.79	1.17	15.99	18.67
10	Chan	-6.93	-5.87	4.69	3.55	1.18	2.65	3.32	1.32	19.27	25.48
11	Chan	-5.87	-4.8	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
12	Chan	-4.8	-3.73	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
13	Chan	-3.73	-2.67	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
14	Chan	-2.67	-1.6	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
15	Chan	-1.6	-0.53	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
16	Chan	-0.53	0.53	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
17	Chan	0.53	1.6	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
18	Chan	1.6	2.67	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
19	Chan	2.67	3.73	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
20	Chan	3.73	4.8	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
21	Chan	4.8	5.87	5.53	3.76	1.07	3.12	3.53	1.47	22.57	33.16
22	Chan	5.87	6.93	4.69	3.55	1.18	2.65	3.32	1.32	19.27	25.48
23	Chan	6.93	8	3.48	2.98	1.19	1.97	2.79	1.17	15.99	18.67
24	ROB	8	11	7.27	7.55	3.09	4.11	2.52	0.96	15.63	15.05
25	ROB	11	13.32	1.56	3.87	2.55	0.88	1.67	0.4	9.69	3.9
26	ROB	13.32	15.65	0.29	1.4	2.55	0.16	0.6	0.2	3.52	0.72
27	ROB	15.65	17.97	0	0.01	0.18	0	0.04	0.03	0.21	0.01
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CONTRACTED CHANNEL SECTION

River Station 1962

CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 100 Year

E.G. Elev (m)	114.37	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.22	Wt. n-Val.		0.043		
W.S. Elev (m)	114.15	Reach Len. (m)	17.4	17.4	17.4	
Crit W.S. (m)	112.7	Flow Area (m2)		84.65		
E.G. Slope (m/m)	0.002329	Area (m2)		84.65		84.65
Q Total (m3/s)	176.98	Flow (m3/s)		176.98		
Top Width (m)	31.45	Top Width (m)		31.45		
Vel Total (m/s)	2.09	Avg. Vel. (m/s)		2.09		
Max Chl Dpth (m)	3.5	Hydr. Depth (m)		2.69		2.69
Conv. Total (m3/s)	3667.5	Conv. (m3/s)		3667.5		
Length Wtd. (m)	17.4	Wetted Per. (m)		33.02		
Min Ch El (m)	110.65	Shear (N/m2)		58.53		
Alpha	1	Stream Power (N/m s)	1385.59	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	9.82	68.03	4.23	
C & E Loss (m)	0.06	Cum SA (1000 m2)	23.49	28.8	6.51	

			Flow dis.	*manual*
		Left WS Sta.		-18.46
		Left Flood Sta.	(data)	-18.46
		Left Main Channel	-12.76	
		Right Main Channel	7.76	
		Right Flood Sta.	(data)	12.99
		Right WS Sta.		12.99
L' (left)	5.7	L (left)		5.7
L' (Right)	5.23	L (Right)		5.23

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		11.16	8.09		
Main	20.52	157.06	69.73	3.40	2.25
Right		8.73	6.84		

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 100 Year

Pos		Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	Chan	-20.22	-18.36	0	0	0.11	0	0.02	0.04	0.5	0.02
2	Chan	-18.36	-16.49	0.6	0.96	2.09	0.34	0.52	0.63	10.52	6.58
3	Chan	-16.49	-14.63	3.21	2.7	2.08	1.82	1.45	1.19	29.55	35.21
4	Chan	-14.63	-12.76	7.35	4.43	2.09	4.15	2.38	1.66	48.53	80.49
5	Chan	-12.76	-10.9	12.25	5.85	1.94	6.92	3.14	2.09	68.8	144.03
6	Chan	-10.9	-9.03	13.62	6.14	1.87	7.7	3.29	2.22	75.07	166.55
7	Chan	-9.03	-7.17	14.3	6.32	1.87	8.08	3.39	2.26	77.28	174.84
8	Chan	-7.17	-5.3	14.95	6.49	1.87	8.45	3.48	2.3	79.39	182.84
9	Chan	-5.3	-3.44	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77
10	Chan	-3.44	-1.57	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77
11	Chan	-1.57	0.3	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77
12	Chan	0.3	2.16	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77
13	Chan	2.16	4.03	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77
14	Chan	4.03	5.89	15.09	6.53	1.87	8.53	3.5	2.31	79.89	184.77
15	Chan	5.89	7.76	11.4	5.75	2.07	6.44	3.08	1.98	63.37	125.59
16	Chan	7.76	9.62	6.23	4.01	2.09	3.52	2.15	1.55	43.92	68.16
17	Chan	9.62	11.49	2.36	2.27	2.09	1.34	1.22	1.04	24.83	25.87
18	Chan	11.49	13.35	0.14	0.56	1.68	0.08	0.37	0.24	7.65	1.85
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PROJECT NO. 151-273 **BRIDGE NO.** 06591 **UNIT:** Metric

Ref. HEC-18., May 2001 (4th ed.)

SUMMARY

Contraction Scour		Type:	**LIVE-BED**	Depth:	**0.75** m	Event:	**500-YR**
Local	**West Abut. #1**	**LEFT**	Eq.: Froehlich	Depth:	**0.68** m	Event:	**500-YR**
Abutment	**East Abut. #2**	**RIGHT**	Eq.: Froehlich	Depth:	**0.47** m	Event:	**500-YR**

CONTRACTION SCOUR

$V_c = K_u\, y^{1/6}\, D^{1/3}$ ……Eq. 5.1

= 1.54 *m/s* Critacal velocity above which bed material of size D and smaller will be transported

Ku = 6.19 m (6.19 in SI units; 11.17 in English units)

y = 3.32 m Average depth of flow upstream of the bridge

D = 0.0084 m Particle size for Vc , *m* (use D_{50})

V1 = 3.10 *m/s* The mean velocity of the flow in the main channel or overbank area upstream of the brige opening

Vc < V1 ***Thus, LIVE-BED CONTRACTION SCOUR***

Live-Bed Contraction Scour ==========

$Y_2/Y_1 = (Q_2/Q_1)^{6/7}\,(W_1/W_2)^{k_1}$ = 1.18 ……Eq. 5.2

$Y_s = Y_2 - Y_o$ m ……Eq. 5.3

= 0.75 m Average contraction scour depth

Y_1 = 3.32 m Average depth in the upstream main channel

Y_2 = 3.91 m Average depth in the contracted section

Y_o = 3.16 m Existing depth in the contracted section before scour

Q_1 = 269.01 m3/s Flow in the upstream channel transporting sediment

Q_2 = 268.40 m3/s Flow in the contracted channel

W_1 = 35.39 m Bottom width of the upstream main channel that is transporting bed material

W_2 = 27.36 m Bottom width of the main channel in the contracted section less pier width

k_1 = 0.64 Exponent determined below (V^*/ω = 0.75)

V^* = 0.3239 $=(T_o/\rho)^{1/2}$ or $(gY1\ S1)^{1/2}$, shear velocity in the upstream section , m/s

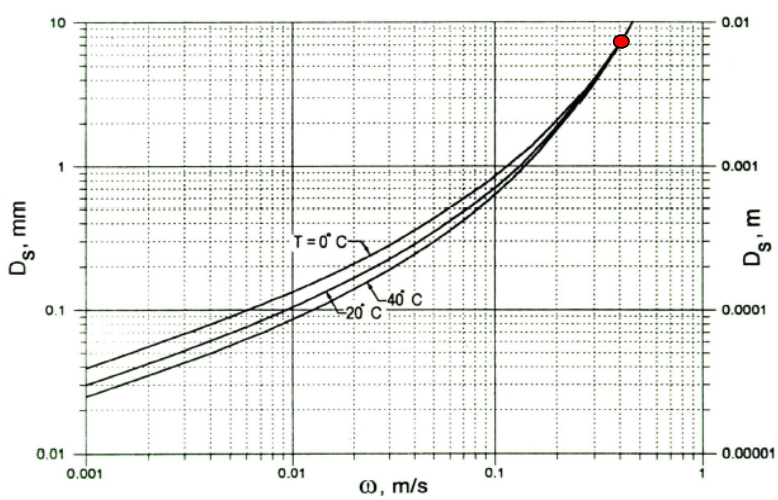
ω = 0.43 m/s Fall velocity of bed material based on the D_{50} (Figure 5.8)

g = 9.81 m/s^2 Acceleration of gravity

S1 = 0.002647 m/m Slope of energy gradeline of main channel

T_o = 104.94 Pa (N/m^2) Shear stess on the bed

ρ = 1000 kg/m^3 Density of water



V/ω*	*k1*	*Mode of Bed Material Transport*
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

Figure 5.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Clear-Water Contraction Scour ==========

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2} \right]^{3/7}$$ .....Eq. 5.4

$$y_s = y_2 - y_o$$ **m** .....Eq. 5.5

=	**N/A**	**m**	Average contraction scour depth **LIVE-BED controls. Ignore this procedure**
y_2 =	5.37	m	Average equilibrium depth in the contracted section after contraction scour
y_o =	3.16	m	Average existing depth in the contracted section
Q =	269.01	m3/s	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W
W =	27.36	m	Bottom width of the contracted section less pier widths
K_u =	0.0250		(0.025 in SI units; 0.0077 in English units)
D_m =	0.0105	m	Diameter of the smallest nontransportable particle in the bed material (1.25 D_{50}) in th contacted setion
D_{50} =	0.0084	m	Median diameter of bed material

Because D_{50} is not the largest particle in the bed material, the scoured section can be slightly armored. Therefore, the D_m is assumed to be 1.25 D_{50}. For stratified bed material the depth of scour can be determined by using the clear-water scour equation sequentially with successive D_m of the bed material layers.

Data Source

Eq. 5.1			From:	RS
y =	3.32	m	C	1962
V1 =	3.10	m	C	1938.5 BR U

Eq. 5.2 & 5.3				
Y1 =	3.32	m	C	1962
Yo =	3.16	m	C	1938.5 BR U
Q1 =	269.01	m3/s	C	1962
Q2 =	268.4	m3/s	C	1938.5 BR U
W1 =	35.39	m	C	1962
or	(n/a)	m (manual)		
W2 =	27.36	m	C	1938.5 BR U
or	(n/a)	m (manual)		
S1 =	0.002647	m/m	C	1962
To =	104.94	Pa (N/m^2)	C	1938.5 BR U
P2 =	0	m (pier width)		

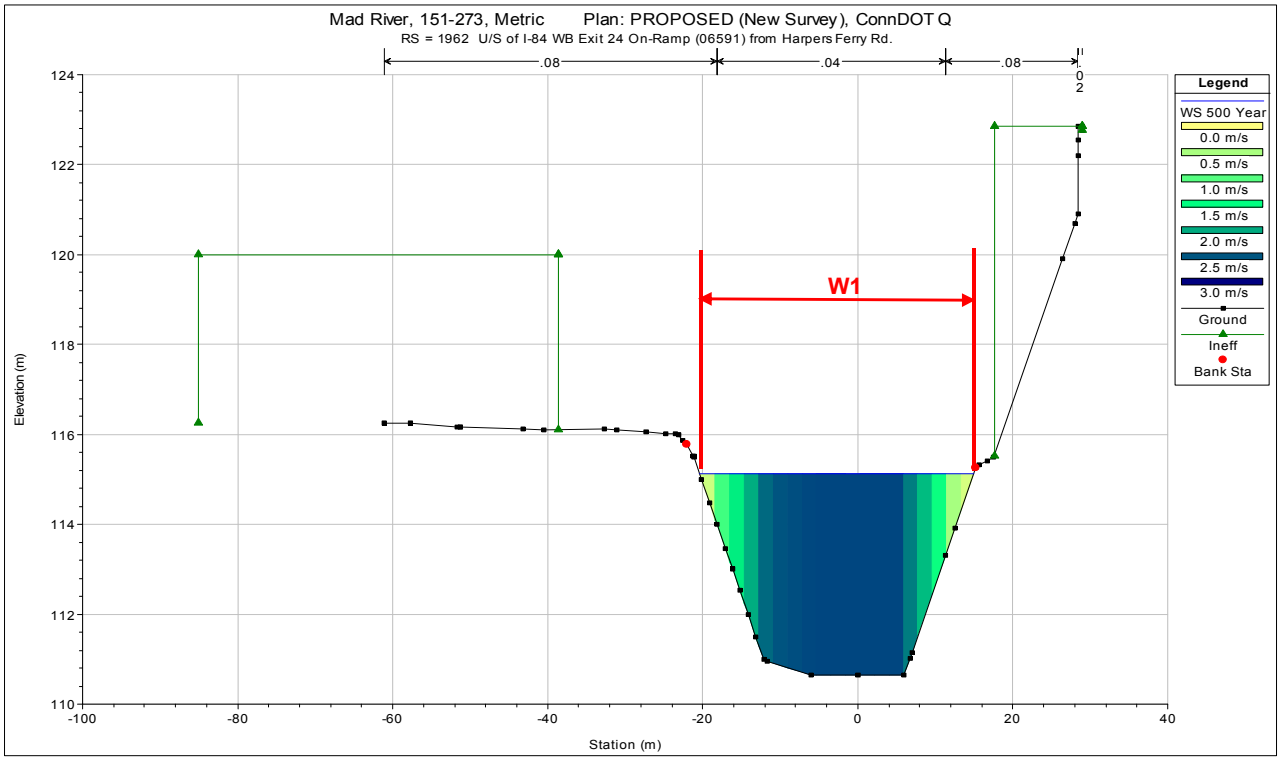
Eq. 5.4 & 5.5				
Q =	269.01	m3/s	C	1938.5

Legends:

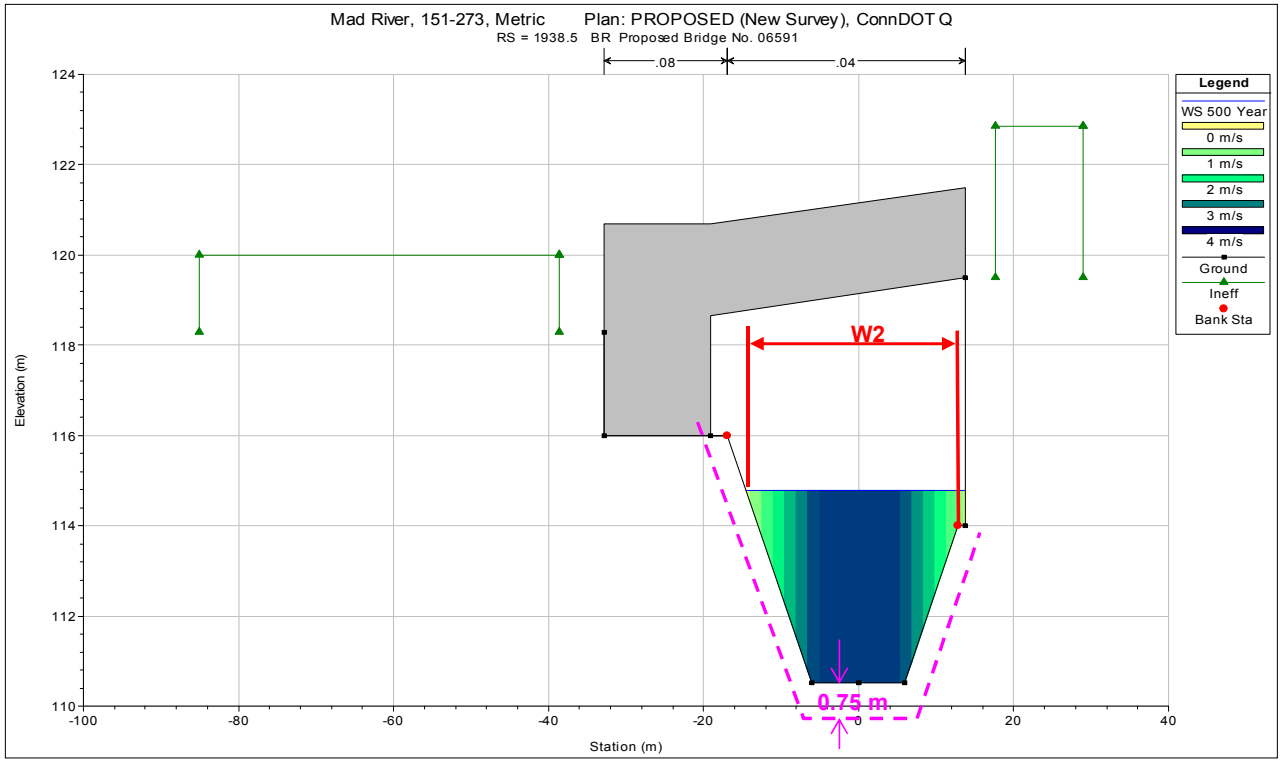
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Outputn and resetting "Channel" and "Overbanks" limits
M	manual data entry

Cross Sections used for Constraction Scour Computations

UPSTREAM SECTION 1962



CONTRACTED SECTION 1938.5 BR U



UPSTREAM CHANNEL SECTION

River Station 1962 Event: 500-YR

HEC-RAS CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 500 Year

E.G. Elev (m)	115.4	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.27	Wt. n-Val.		0.048		
W.S. Elev (m)	115.13	Reach Len. (m)	17.4	17.4	17.4	
Crit W.S. (m)	113.29	Flow Area (m2)		117.61		
E.G. Slope (m/m)	0.002647	Area (m2)		117.61		117.61
Q Total (m3/s)	269.01	Flow (m3/s)		269.01		
Top Width (m)	35.39	Top Width (m)		35.39		
Vel Total (m/s)	2.29	Avg. Vel. (m/s)		2.29		
Max Chl Dpth (m)	4.48	Hydr. Depth (m)		3.32		3.32
Conv. Total (m3/s)	5229.1	Conv. (m3/s)		5229.1		
Length Wtd. (m)	17.4	Wetted Per. (m)		37.44		
Min Ch El (m)	110.65	Shear (N/m2)		81.53		
Alpha	1	Stream Power (N/m s)	1385.59	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	34.27	88.5	12.37	
C & E Loss (m)	0.07	Cum SA (1000 m2)	48.44	28.86	14.6	

		Flow dis.	*manual*
Left WS Sta.			-20.43
Left Flood Sta.		(data)	-20.43
Left Main Channel		-12.76	
Right Main Channel		7.76	
Right Flood Sta.		(data)	14.97
Right WS Sta.			14.97
L' (left)	7.67	L (left)	7.67
L' (Right)	7.21	L (Right)	7.21

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		23.16	14.68		
Main	20.52	227.5	89.97	4.38	2.53
Right		18.38	12.98		

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	Chan	-22.09	-20.22	0	0.01	0.23	0	0.05	0.06	1.18	0.07
2	Chan	-20.22	-18.36	0.32	1.06	2.09	0.12	0.57	0.3	13.2	4
3	Chan	-18.36	-16.49	3.16	2.8	2.09	1.17	1.5	1.13	34.85	39.3
4	Chan	-16.49	-14.63	7.25	4.54	2.08	2.69	2.43	1.6	56.5	90.25
5	Chan	-14.63	-12.76	12.43	6.27	2.09	4.62	3.36	1.98	78.04	154.63
6	Chan	-12.76	-10.9	18.31	7.69	1.94	6.81	4.12	2.38	102.78	244.66
7	Chan	-10.9	-9.03	19.98	7.98	1.87	7.43	4.28	2.5	110.87	277.61
8	Chan	-9.03	-7.17	20.74	8.16	1.87	7.71	4.38	2.54	113.4	288.22
9	Chan	-7.17	-5.3	21.47	8.33	1.87	7.98	4.47	2.58	115.8	298.47
10	Chan	-5.3	-3.44	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
11	Chan	-3.44	-1.57	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
12	Chan	-1.57	0.3	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
13	Chan	0.3	2.16	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
14	Chan	2.16	4.03	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
15	Chan	4.03	5.89	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
16	Chan	5.89	7.76	17.16	7.59	2.07	6.38	4.07	2.26	95.05	214.78
17	Chan	7.76	9.62	11.07	5.85	2.09	4.12	3.14	1.89	72.8	137.69
18	Chan	9.62	11.49	5.92	4.11	2.09	2.2	2.2	1.44	51.11	73.68
19	Chan	11.49	13.35	1.23	2.37	2.09	0.46	1.27	0.52	29.47	15.25
20	Chan	13.35	15.22	0.16	0.65	1.8	0.06	0.4	0.24	9.34	2.25
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CONTRACTED CHANNEL SECTION

River Station 1938.5 BR U

CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 500 Year

E.G. Elev (m)	115.28	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.49	Wt. n-Val.		0.04	0.04	
W.S. Elev (m)	114.79	Reach Len. (m)	12.8	12.8	12.8	
Crit W.S. (m)	113.64	Flow Area (m2)		86.58	0.72	
E.G. Slope (m/m)	0.003608	Area (m2)		86.58	0.72	87.3
Q Total (m3/s)	269.01	Flow (m3/s)		268.4	0.61	
Top Width (m)	28.27	Top Width (m)		27.36	0.91	
Vel Total (m/s)	3.08	Avg. Vel. (m/s)		3.1	0.85	
Max Chl Dpth (m)	4.26	Hydr. Depth (m)		3.16	0.79	3.09
Conv. Total (m3/s)	4478.5	Conv. (m3/s)		4468.3	10.2	
Length Wtd. (m)	12.8	Wetted Per. (m)		29.19	1.7	
Min Ch El (m)	110.53	Shear (N/m2)		104.94	14.99	
Alpha	1.01	Stream Power (N/m s)	658.33	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	34.27	86.72	12.36	
C & E Loss (m)	0.01	Cum SA (1000 m2)	48.44	28.32	14.59	

		Flow dis.	*manual*
Left WS Sta.			-14.52
Left Flood Sta.			-14.5
Left Main Channel		-6.51	
Right Main Channel		8.37	
Right Flood Sta.		12.87	13.75
Right WS Sta.			13.75
L' (left)	7.99	L (left)	8.01
L' (Right)	5.38	L (Right)	5.38

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		21.71	10.62		
Main	14.88	229.16	67.33	4.52	3.40
Right		18.16	9.3		

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 500 Year

Pos		Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	Chan	-15.44	-13.95	0.03	0.08	0.63	0.01	0.14	0.34	4.46	1.51
2	Chan	-13.95	-12.46	0.92	0.97	1.66	0.34	0.65	0.94	20.71	19.49
3	Chan	-12.46	-10.98	3.25	2.08	1.66	1.21	1.4	1.56	44.28	69.14
4	Chan	-10.98	-9.49	6.62	3.19	1.66	2.46	2.14	2.08	67.85	140.81
5	Chan	-9.49	-8	10.89	4.3	1.66	4.05	2.89	2.53	91.42	231.44
6	Chan	-8	-6.51	15.96	5.41	1.66	5.93	3.63	2.95	114.99	339.21
7	Chan	-6.51	-5.02	21.46	6.28	1.55	7.98	4.22	3.42	143.44	490.3
8	Chan	-5.02	-3.53	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
9	Chan	-3.53	-2.05	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
10	Chan	-2.05	-0.56	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
11	Chan	-0.56	0.93	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
12	Chan	0.93	2.42	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
13	Chan	2.42	3.91	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
14	Chan	3.91	5.4	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
15	Chan	5.4	6.89	20.3	6.15	1.6	7.54	4.13	3.3	136.24	449.95
16	Chan	6.89	8.37	14.5	5.11	1.67	5.39	3.44	2.84	108.39	307.39
17	Chan	8.37	9.86	9.59	3.99	1.67	3.56	2.68	2.4	84.57	203.24
18	Chan	9.86	11.35	5.52	2.87	1.67	2.05	1.92	1.93	60.74	117.07
19	Chan	11.35	12.84	2.41	1.74	1.67	0.9	1.17	1.38	36.91	51.04
20	ROB	12.84	12.93	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
21	ROB	12.93	13.02	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
22	ROB	13.02	13.11	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
23	ROB	13.11	13.2	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
24	ROB	13.2	13.3	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
25	ROB	13.3	13.39	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
26	ROB	13.39	13.48	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
27	ROB	13.48	13.57	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
28	ROB	13.57	13.66	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
29	ROB	13.66	13.75	0.01	0.07	0.88	0.01	0.79	0.2	2.89	0.58
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LIVE SCOUR AT ABUTMENTS

Froehlich's Live-Bed Abutment Scour Equation — *LEFT* — *RIGHT* — ==========

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 1 =$ — **2.94** — **2.11** — .....Eq. 7.1

Amended Local Scour Equation

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 0.05 =$ — **1.99** — **1.16** — .....CT DOT DM Pg 9B-2

	LEFT	RIGHT		
Ys =	**0.68**	**0.47**	**m**	Scour depth <== using Amended equation
K_1 =	1.00	1.00		Coeffcient for abutment shape (see Table 7.1 and Figrue 7.6)
K_2 =	0.91	0.96		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
θ =	45*	66		*For the part that interacts with the flow; The overall embankment angle is at 160;
				θ < 90 degrees if embankment points downstream
				θ > 90 degrees if embankment points upstream
				(see Figure 7.5 for definition of θ)
L' =	0.94	1.62	m	Length of active flow obstructed by the embankment (see Figure 7.4)
Ae =	0.32	0.65	m^2	Flow area of the approach cross section obstructed by the embankment
Fr =	0.44	0.12		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment
Ve =	0.81	0.25	m/s	Qe/Ae
Qe =	0.26	0.16	m^3/s	Flow obstructed by the abutment and approach embankment
Ya =	0.34	0.40	m	Ae/L, Average depth of flow on the floodplain
L =	0.9425	1.62	m	Length of embankment projected normal to the flow

Table 7.1. Abutment Shape Coefficients.

Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

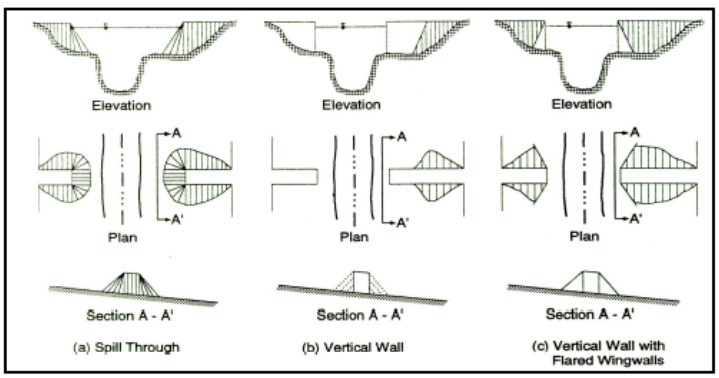


Figure 7.6. Abutment shape.

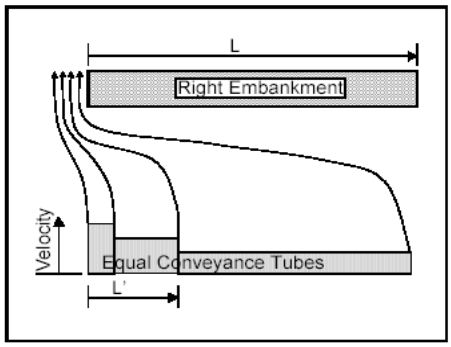


Figure 7.4. Determination of length of embankment blocking live flow for abutment scour estimation.

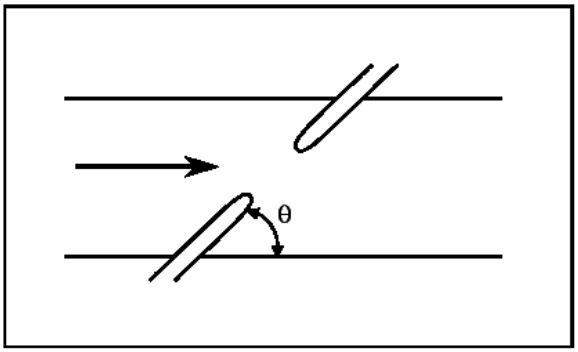


Figure 7.5. Orientation of embankment angle, θ, to the flow.

HIRE Live-Bed Abutment Scour Equation ==========

		LEFT	RIGHT	
Applicability check:	L/Y_1 =	0	0	*Use HIRE Eq. only if L/Y_1 > 25*
$Y_s/Y_1 = 4\ Fr^{0.33}\ K_1/0.55\ K_2$ =		**N/A**	**N/A**	.....Eq. 7.1

	LEFT	RIGHT		
Ys =	**N/A**	**N/A**	**m**	Scour depth (N/A if L/Y_1 < 25)
K1 =	1.00	1.00		Coeffcient for abutment shape (see Table 7.1 on RIGHT)
K2 =	0.91	0.96		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
Y1 =	3.32	3.32	m	Depth of flow at the abutment on the overbank or in the main channel,
Fr =	0.44	0.12		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment

Data Source

Eq. 7.1			From:	RS
LT			UF	
	L' =	0.94 m	D	1938.5 BR U
	Ae =	0.32 m2	D	1938.5 BR U
	Qe =	0.26 m3/s	D	1938.5 BR U
	L =	0.94 m	D	1938.5 BR U
RT			UC	
	L' =	1.62 m	D	1962
	Ae =	0.65 m2	D	1962
	Qe =	0.16 m3/s	D	1962
	L =	1.62 m	D	1962

Legends:

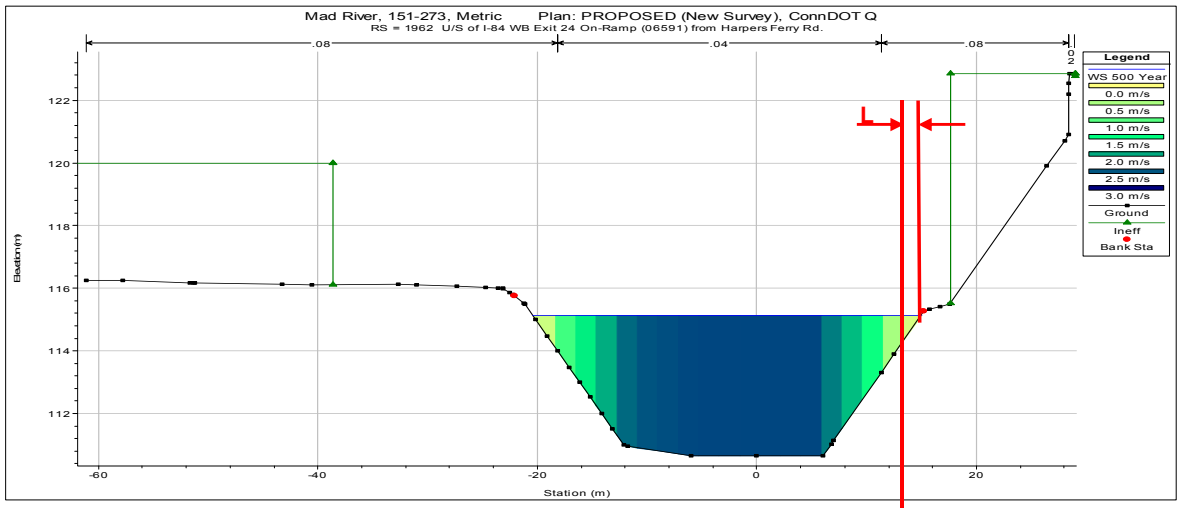
UC	from an upstream Cross Section output (approach section)
UF	from Bridge Upstream Face - Cross Section output (BR U); or Bridge Downstream Face (BR D) - this is seldom used
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Outputn and resetting "Channel" and "Overbanks" limits
M	manual data entry

Cross Sections Used for Local Abutment Scour Computations -

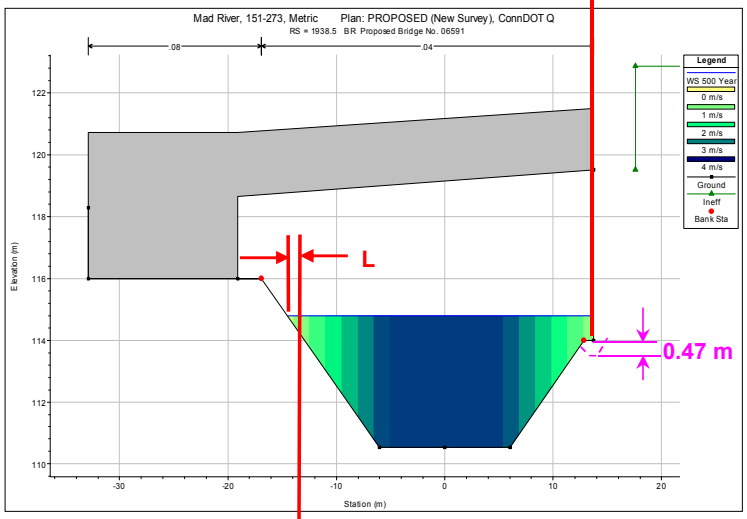
WEST ABUTMENT #1 (LEFT)

EAST ABUTMENT #2 (RIGHT)

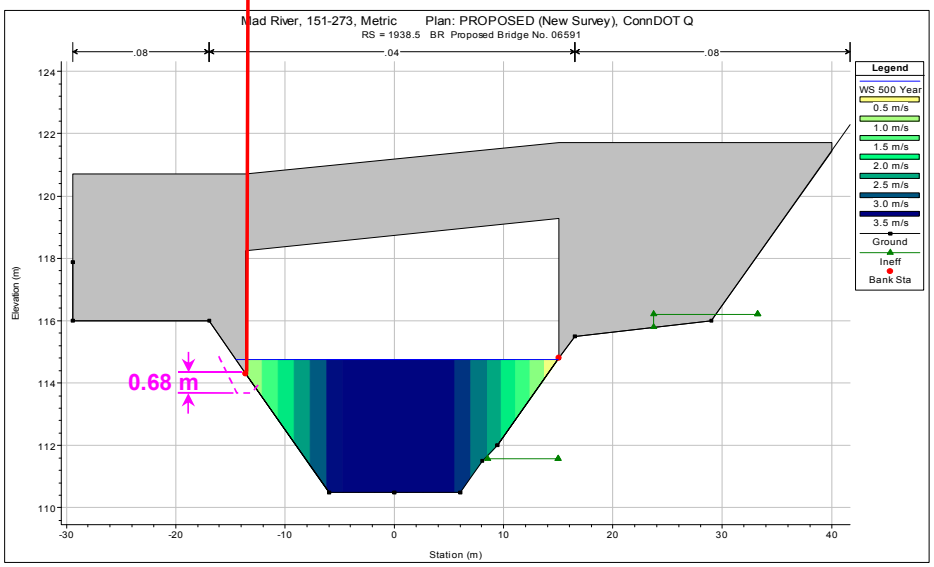
APPROACH SECTION 1938.5 BR U



LT: APPROACH SECTION **1938.5 BR U** **RT: BRIDGE SECTION**



BRIDGE SECTION 1938.5 BR D



UPSTREAM APPROACH CHANNEL SECTION

River Station 1962 Event: 500-YR

CROSS SECTION OUTPUT ***Use the same data as in the contraction scour computation?*** No

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 500 Year

E.G. Elev (m)	115.4	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.27	Wt. n-Val.		0.048		
W.S. Elev (m)	115.13	Reach Len. (m)	17.4	17.4	17.4	
Crit W.S. (m)	113.29	Flow Area (m2)		117.61		
E.G. Slope (m/m)	0.002647	Area (m2)		117.61		117.61
Q Total (m3/s)	269.01	Flow (m3/s)		269.01		
Top Width (m)	35.39	Top Width (m)		35.39		
Vel Total (m/s)	2.29	Avg. Vel. (m/s)		2.29		
Max Chl Dpth (m)	4.48	Hydr. Depth (m)		3.32		3.32
Conv. Total (m3/s)	5229.1	Conv. (m3/s)		5229.1		
Length Wtd. (m)	17.4	Wetted Per. (m)		37.44		
Min Ch El (m)	110.65	Shear (N/m2)		81.53		
Alpha	1	Stream Power (N/m s)	1385.59	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	34.27	88.5	12.37	
C & E Loss (m)	0.07	Cum SA (1000 m2)	48.44	28.86	14.6	

		Flow dis.	*manual*
Left WS Sta.			-20.43
Left Flood Sta.		(data)	-20.43
Left Main Channel		-20.22	
Right Main Channel		13.35	
Right Flood Sta.		(data)	14.97
Right WS Sta.			14.97
L' (left)	0.21	L (left)	0.21
L' (Right)	1.62	L (Right)	1.62

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		0	0.01		
Main	33.57	268.88	116.97	3.48	2.30
Right		0.16	0.65		

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)		
1	Chan	-22.09	-20.22	0	0.01	0.23	0	0.05	0.06	1.18	0.07
2	Chan	-20.22	-18.36	0.32	1.06	2.09	0.12	0.57	0.3	13.2	4
3	Chan	-18.36	-16.49	3.16	2.8	2.09	1.17	1.5	1.13	34.85	39.3
4	Chan	-16.49	-14.63	7.25	4.54	2.08	2.69	2.43	1.6	56.5	90.25
5	Chan	-14.63	-12.76	12.43	6.27	2.09	4.62	3.36	1.98	78.04	154.63
6	Chan	-12.76	-10.9	18.31	7.69	1.94	6.81	4.12	2.38	102.78	244.66
7	Chan	-10.9	-9.03	19.98	7.98	1.87	7.43	4.28	2.5	110.87	277.61
8	Chan	-9.03	-7.17	20.74	8.16	1.87	7.71	4.38	2.54	113.4	288.22
9	Chan	-7.17	-5.3	21.47	8.33	1.87	7.98	4.47	2.58	115.8	298.47
10	Chan	-5.3	-3.44	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
11	Chan	-3.44	-1.57	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
12	Chan	-1.57	0.3	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
13	Chan	0.3	2.16	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
14	Chan	2.16	4.03	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
15	Chan	4.03	5.89	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
16	Chan	5.89	7.76	17.16	7.59	2.07	6.38	4.07	2.26	95.05	214.78
17	Chan	7.76	9.62	11.07	5.85	2.09	4.12	3.14	1.89	72.8	137.69
18	Chan	9.62	11.49	5.92	4.11	2.09	2.2	2.2	1.44	51.11	73.68
19	Chan	11.49	13.35	1.23	2.37	2.09	0.46	1.27	0.52	29.47	15.25
20	Chan	13.35	15.22	0.16	0.65	1.8	0.06	0.4	0.24	9.34	2.25
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BRIDGE SECTION

River Station 1938.5 BR U

CROSS SECTION OUTPUT ***Use the same data as in the contraction scour computation?*** No

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 500 Year

E.G. Elev (m)	115.28	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.49	Wt. n-Val.		0.04	0.04	
W.S. Elev (m)	114.79	Reach Len. (m)	12.8	12.8	12.8	
Crit W.S. (m)	113.64	Flow Area (m2)		86.58	0.72	
E.G. Slope (m/m)	0.003608	Area (m2)		86.58	0.72	87.3
Q Total (m3/s)	269.01	Flow (m3/s)		268.4	0.61	
Top Width (m)	28.27	Top Width (m)		27.36	0.91	
Vel Total (m/s)	3.08	Avg. Vel. (m/s)		3.1	0.85	
Max Chl Dpth (m)	4.26	Hydr. Depth (m)		3.16	0.79	3.09
Conv. Total (m3/s)	4478.5	Conv. (m3/s)		4468.3	10.2	
Length Wtd. (m)	12.8	Wetted Per. (m)		29.19	1.7	
Min Ch El (m)	110.53	Shear (N/m2)		104.94	14.99	
Alpha	1.01	Stream Power (N/m s)	658.33	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	34.27	86.72	12.36	
C & E Loss (m)	0.01	Cum SA (1000 m2)	48.44	28.32	14.59	

	Flow dis.	*manual*
Left WS Sta.		-14.52
Left Flood Sta.		-14.52
Left Main Channel	-13.5775	
Right Main Channel	13.75	
Right Flood Sta.	12.87	13.75
Right WS Sta.		13.75

L' (left)	0.9425	L (left)	0.9425
L' (Right)	0	L (Right)	0

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		0.26	0.3225		
Main	27.3275	268.77	86.9275	3.18	3.09
Right		0	0		

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR U Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	Chan	-15.44	-13.95	0.03	0.08	0.63	0.01	0.14	0.34	4.46	1.51
2	Chan	-13.95	-12.46	0.92	0.97	1.66	0.34	0.65	0.94	20.71	19.49
3	Chan	-12.46	-10.98	3.25	2.08	1.66	1.21	1.4	1.56	44.28	69.14
4	Chan	-10.98	-9.49	6.62	3.19	1.66	2.46	2.14	2.08	67.85	140.81
5	Chan	-9.49	-8	10.89	4.3	1.66	4.05	2.89	2.53	91.42	231.44
6	Chan	-8	-6.51	15.96	5.41	1.66	5.93	3.63	2.95	114.99	339.21
7	Chan	-6.51	-5.02	21.46	6.28	1.55	7.98	4.22	3.42	143.44	490.3
8	Chan	-5.02	-3.53	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
9	Chan	-3.53	-2.05	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
10	Chan	-2.05	-0.56	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
11	Chan	-0.56	0.93	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
12	Chan	0.93	2.42	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
13	Chan	2.42	3.91	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
14	Chan	3.91	5.4	22.42	6.34	1.49	8.34	4.26	3.53	150.81	532.99
15	Chan	5.4	6.89	20.3	6.15	1.6	7.54	4.13	3.3	136.24	449.95
16	Chan	6.89	8.37	14.5	5.11	1.67	5.39	3.44	2.84	108.39	307.39
17	Chan	8.37	9.86	9.59	3.99	1.67	3.56	2.68	2.4	84.57	203.24
18	Chan	9.86	11.35	5.52	2.87	1.67	2.05	1.92	1.93	60.74	117.07
19	Chan	11.35	12.84	2.41	1.74	1.67	0.9	1.17	1.38	36.91	51.04
20	ROB	12.84	12.93	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
21	ROB	12.93	13.02	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
22	ROB	13.02	13.11	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
23	ROB	13.11	13.2	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
24	ROB	13.2	13.3	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
25	ROB	13.3	13.39	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
26	ROB	13.39	13.48	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
27	ROB	13.48	13.57	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
28	ROB	13.57	13.66	0.07	0.07	0.09	0.02	0.79	0.92	28.03	25.75
29	ROB	13.66	13.75	0.01	0.07	0.88	0.01	0.79	0.2	2.89	0.58
30											
31											
32											
33											
34											
35											

BRIDGE OUTPUT

River Station 1938.5

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 Profile: 500 Year

E.G. US. (m)	115.4	Element	Inside BR US	Inside BR DS
W.S. US. (m)	115.13	E.G. Elev (m)	115.28	115.22
Q Total (m3/s)	269.01	W.S. Elev (m)	114.79	114.76
Q Bridge (m3/s)	269.01	Crit W.S. (m)	113.64	113.56
Q Weir (m3/s)		Max Chl Dpth (m)	4.26	4.28
Weir Sta Lft (m)		Vel Total (m/s)	3.08	3.03
Weir Sta Rgt (m)		Flow Area (m2)	87.31	88.82
Weir Submerg		Froude # Chl	0.56	0.55
Weir Max Depth (m)		Specif Force (m3)	245.18	246.62
Min El Weir Flow (m)	120.7	Hydr Depth (m)	3.09	3.11
Min El Prs (m)	119.5	W.P. Total (m)	30.9	30.45
Delta EG (m)	0.34	Conv. Total (m3/s)	4478.5	4533.6
Delta WS (m)	0.39	Top Width (m)	28.27	28.56
BR Open Area (m2)	203.36	Frctn Loss (m)	0.05	0.09
BR Open Vel (m/s)	3.08	C & E Loss (m)	0.01	0.08
Coef of Q		Shear Total (N/m2)	99.98	100.73
Br Sel Method	Energy only	Power Total (N/m s)	-1572.79	-1409.04

BRIDGE SECTION

River Station 1938.5 BR D

CROSS SECTION OUTPUT

Use the same data as in the contraction scour computation? No

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR D Profile: 500 Year

E.G. Elev (m)	115.22	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.47	Wt. n-Val.		0.04		
W.S. Elev (m)	114.76	Reach Len. (m)	31.7	31.7	31.7	
Crit W.S. (m)	113.56	Flow Area (m2)		88.82		
E.G. Slope (m/m)	0.003521	Area (m2)		88.82		88.82
Q Total (m3/s)	269.01	Flow (m3/s)		269.01		
Top Width (m)	28.56	Top Width (m)		28.56		
Vel Total (m/s)	3.03	Avg. Vel. (m/s)		3.03		
Max Chl Dpth (m)	4.28	Hydr. Depth (m)		3.11		3.11
Conv. Total (m3/s)	4533.6	Conv. (m3/s)		4533.6		
Length Wtd. (m)	31.7	Wetted Per. (m)		30.45		
Min Ch El (m)	110.48	Shear (N/m2)		100.73		
Alpha	1	Stream Power (N/m s)	2114.77	0	0	
Frctn Loss (m)	0.09	Cum Volume (1000 m3)	34.27	85.6	12.36	
C & E Loss (m)	0.08	Cum SA (1000 m2)	48.44	27.96	14.59	

	Flow dis.	*manual*
Left WS Sta.	-13.57	-14.46
Left Flood Sta.	-13.57	
Left Main Channel	-13.57	
Right Main Channel	14.98	
Right Flood Sta.		14.98
Right WS Sta.	15.08	14.98
L' (left) 0	L (left)	0.89
L' (Right) 0	L (Right)	0

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT					
Main	28.55	269.04	88.79	3.11	3.03
Right					

Plan: PR_DOT Mad River Reach 1 RS: 1938.5 BR D Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	Chan	-13.57	-12.1	1.31	1.22	1.65	0.49	0.83	1.08	25.54	27.49
2	Chan	-12.1	-10.63	3.81	2.31	1.65	1.42	1.57	1.65	48.42	79.85
3	Chan	-10.63	-9.16	7.27	3.4	1.65	2.7	2.31	2.13	71.31	152.21
4	Chan	-9.16	-7.68	11.55	4.5	1.65	4.3	3.06	2.57	94.2	242.06
5	Chan	-7.68	-6.21	16.6	5.59	1.65	6.17	3.8	2.97	117.08	347.82
6	Chan	-6.21	-4.74	21.51	6.28	1.5	8	4.27	3.42	144.89	496.13
7	Chan	-4.74	-3.27	21.83	6.29	1.47	8.11	4.28	3.47	147.68	512.17
8	Chan	-3.27	-1.8	21.83	6.29	1.47	8.11	4.28	3.47	147.68	512.17
9	Chan	-1.8	-0.33	21.83	6.29	1.47	8.11	4.28	3.47	147.68	512.17
10	Chan	-0.33	1.14	21.83	6.29	1.47	8.11	4.28	3.47	147.68	512.17
11	Chan	1.14	2.61	21.83	6.29	1.47	8.11	4.28	3.47	147.68	512.17
12	Chan	2.61	4.09	21.83	6.29	1.47	8.11	4.28	3.47	147.68	512.17
13	Chan	4.09	5.56	21.83	6.29	1.47	8.11	4.28	3.47	147.68	512.17
14	Chan	5.56	7.03	19.32	6.03	1.59	7.18	4.1	3.2	131.04	419.64
15	Chan	7.03	8.5	14.08	5.03	1.62	5.23	3.42	2.8	107.2	300.29
16	Chan	8.5	9.8	9.35	3.71	1.4	3.48	2.86	2.52	91.41	230.27
17	Chan	9.8	11.1	6.17	2.93	1.45	2.29	2.26	2.1	69.76	146.75
18	Chan	11.1	12.4	3.52	2.09	1.45	1.31	1.61	1.68	49.8	83.68
19	Chan	12.4	13.7	1.5	1.25	1.45	0.56	0.97	1.19	29.84	35.64
20	Chan	13.7	15	0.24	0.42	1.44	0.09	0.32	0.57	9.93	5.7
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PROJECT NO. 151-273 **BRIDGE NO.** 06591 **UNIT:** Metric

Ref. HEC-18., May 2001 (4th ed.)

SUMMARY

Contraction Scour	Type: **LIVE-BED**	Depth: **2.27** m	Event: **500-YR**

CONTRACTION SCOUR (RS 1+962)

$V_c = K_u y^{1/6} D^{1/3}$ ……Eq. 5.1

= 1.61 *m/s* Critacal velocity above which bed material of size D and smaller will be transported

K_u = 6.19 m (6.19 in SI units; 11.17 in English units)

y = 4.41 m Average depth of flow upstream of the bridge

D = 0.0084 m Particle size for Vc *, m* (use D_{50})

V1 = 2.53 *m/s* The mean velocity of the flow in the main channel or overbank area upstream of the brige opening

Vc < V1 ***Thus, LIVE-BED CONTRACTION SCOUR***

Live-Bed Contraction Scour ==========

$Y_2/Y_1 = (Q_2/Q_1)^{6/7} (W_1/W_2)^{k_1}$ = 1.51 ……Eq. 5.2

$Y_s = Y_2 - Y_o$ m ……Eq. 5.3

= 2.27 m Average contraction scour depth

Y_1 = 4.41 m Average depth in the upstream main channel

Y_2 = 6.65 m Average depth in the contracted section

Y_o = 4.38 m Existing depth in the contracted section before scour

Q_1 = 116.93 m3/s Flow in the upstream channel transporting sediment

Q_2 = 227.50 m3/s Flow in the contracted channel

W_1 = 16.00 m Bottom width of the upstream main channel that is transporting bed material

W_2 = 20.52 m Bottom width of the main channel in the contracted section less pier width

k_1 = 0.64 Exponent determined below (V^*/ω = 0.66)

V^* = 0.2855 $=(T_o/\rho)^{1/2}$ or $(gY1\ S1)^{1/2}$, shear velocity in the upstream section , m/s

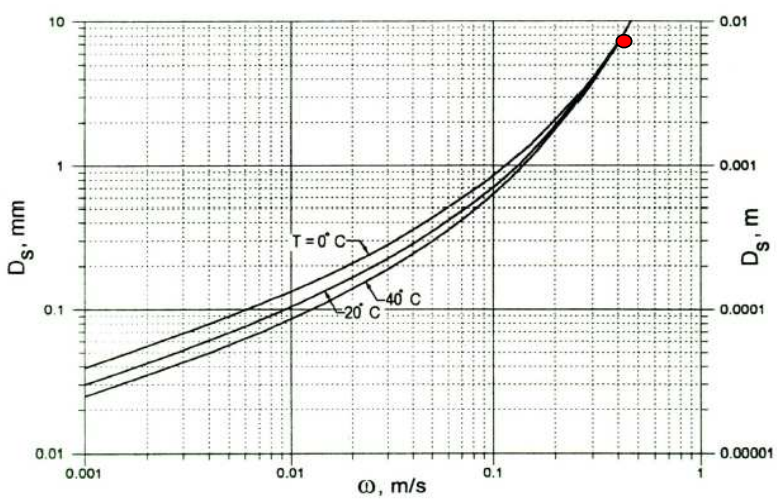
ω = 0.43 m/s Fall velocity of bed material based on the D_{50} (Figure 5.8)

g = 9.81 m/s^2 Acceleration of gravity

S1 = 0.00063 m/m Slope of energy gradeline of main channel

T_o = 81.53 Pa (N/m^2) Shear stess on the bed

ρ = 1000 kg/m^3 Density of water



V^*/ω	k1	*Mode of Bed Material Transport*
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

Figure 5.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Clear-Water Contraction Scour ==========

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2} \right]^{3/7}$$ .....Eq. 5.4

$y_s = y_2 - y_o$ **m** .....Eq. 5.5

=	**N/A**	**m**	Average contraction scour depth **LIVE-BED controls. Ignore this procedure**
y_2 =	6.87	m	Average equilibrium depth in the contracted section after contraction scour
y_o =	4.38	m	Average existing depth in the contracted section
Q =	269.01	m3/s	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W
W =	20.52	m	Bottom width of the contracted section less pier widths
K_u =	0.0250		(0.025 in SI units; 0.0077 in English units)
D_m =	0.0105	m	Diameter of the smallest nontransportable particle in the bed material (1.25 D_{50}) in th contacted setion
D_{50} =	0.0084	m	Median diameter of bed material

Because D_{50} is not the largest particle in the bed material, the scoured section can be slightly armored. Therefore, the D_m is assumed to be 1.25 D_{50}. For stratified bed material the depth of scour can be determined by using the clear-water scour equation sequentially with successive D_m of the bed material layers.

Data Source

Eq. 5.1			From:	RS
y =	4.41	m	C	1983
V1 =	2.53	m	D	1962

Eq. 5.2 & 5.3				
Y1 =	4.41	m	C	1983
Yo =	4.38	m	D	1962
Q1 =	116.93	m3/s	C	1983
Q2 =	227.5	m3/s	D	1962
W1 =	16	m	C	1983
or	(n/a)	m (manual)		
W2 =	20.52	m	D	1962
or	(n/a)	m (manual)		
S1 =	0.00063	m/m	C	1983
To =	81.53	Pa (N/m^2)	C	1962
P2 =	0	m (pier width)		

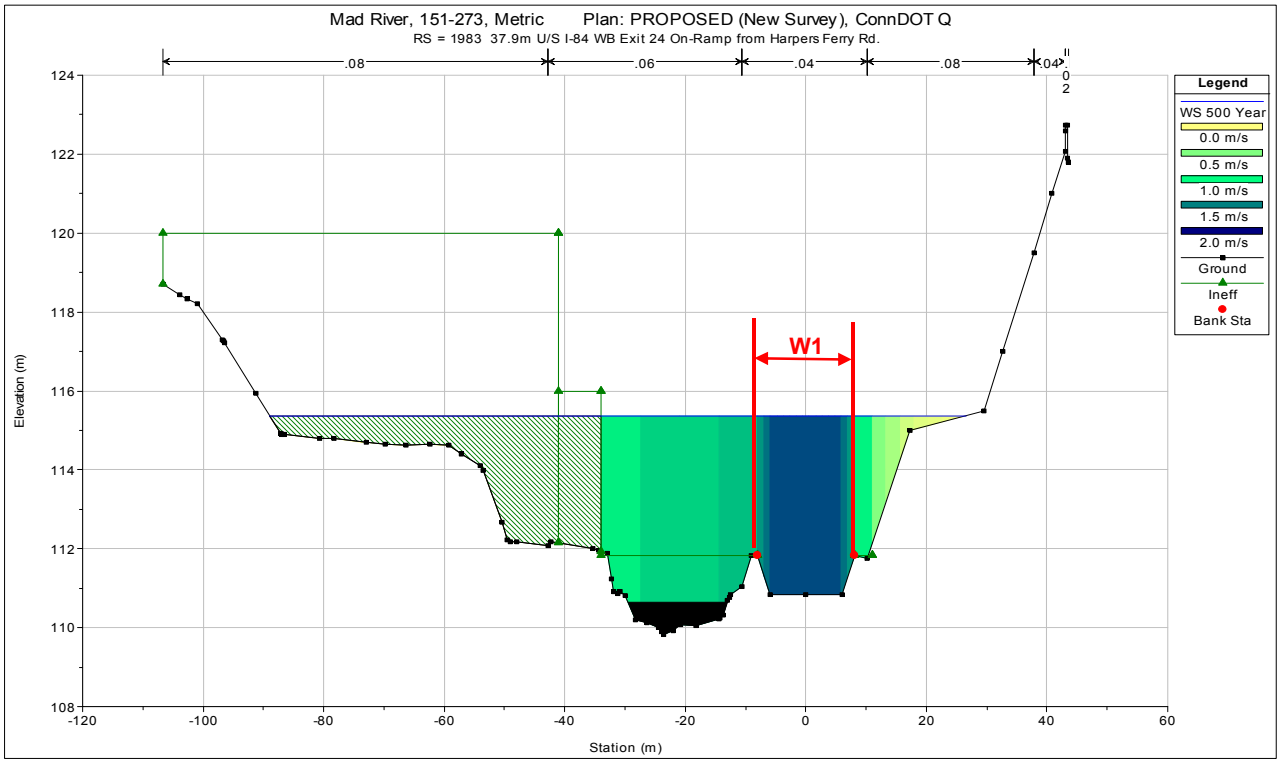
Eq. 5.4 & 5.5			
Q =	269.01	m3/s	M

Legends:

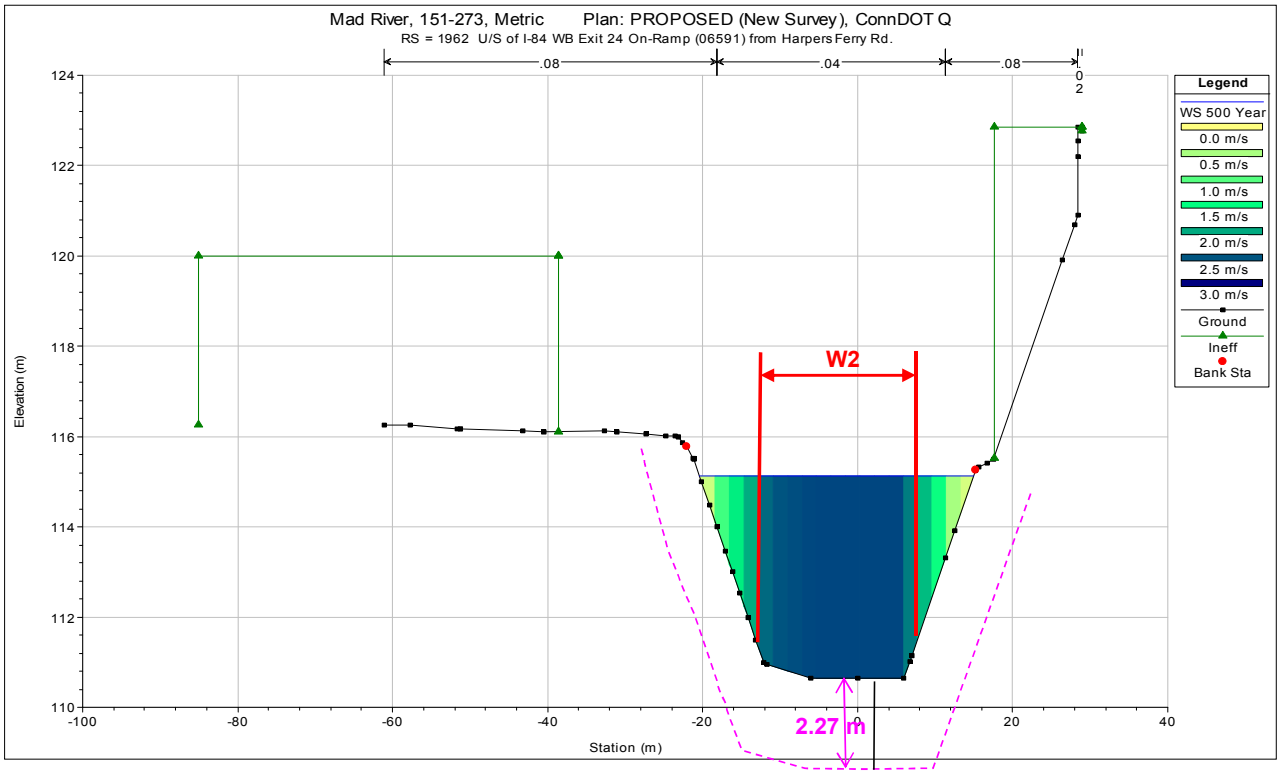
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

Cross Sections used for Constraction Scour Computations

UPSTREAM SECTION 1983



CONTRACTED SECTION 1962



UPSTREAM CHANNEL SECTION

River Station 1983 Event: 500-YR

HEC-RAS CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1983 Profile: 500 Year

			Left OB	Channel	Right OB	Total
E.G. Elev (m)	115.48	Element				
Vel Head (m)	0.1	Wt. n-Val.	0.058	0.04	0.052	
W.S. Elev (m)	115.38	Reach Len. (m)	12	10.3	8.5	
Crit W.S. (m)	112.56	Flow Area (m2)	116.84	70.61	23.46	
E.G. Slope (m/m)	0.00063	Area (m2)	201.27	70.61	23.46	295.34
Q Total (m3/s)	269.01	Flow (m3/s)	136.31	116.93	15.78	
Top Width (m)	115.54	Top Width (m)	80.95	16	18.59	
Vel Total (m/s)	1.28	Avg. Vel. (m/s)	1.17	1.66	0.67	
Max Chl Dpth (m)	4.73	Hydr. Depth (m)	4.51	4.41	1.26	2.56
Conv. Total (m3/s)	10717.8	Conv. (m3/s)	5430.6	4658.5	628.7	
Length Wtd. (m)	10.98	Wetted Per. (m)	26.56	16.47	19.31	
Min Ch El (m)	110.84	Shear (N/m2)	27.18	26.48	7.51	
Alpha	1.17	Stream Power (N/m s)	2083.64	0	0	
Frctn Loss (m)	0.01	Cum Volume (1000 m3)	37.18	90.2	12.6	
C & E Loss (m)	0.02	Cum SA (1000 m2)	49.74	29.29	14.8	

	Flow dis.	*manual*
Left WS Sta.	-60.72	-88.95
Left Convy Sta.	-33.9	
Left Main Channel	-8	
Right Main Channel	8	
Right Convy Sta.	15.65	
Right WS Sta.		26.59
L' (left) 25.9	L (left)	80.95
L' (Right) 7.65	L (Right)	18.59

HEC-RAS FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		136.3	201.26		
Main	16	116.9	70.6	4.41	1.65
Right		15.77	23.46		

Plan: PR_DOT Mad River Reach 1 RS: 1983 Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	-93.58	-87	0	0.45	2	0	0.23	0	1.39	0
2	LOB	-87	-80.43	0	3.43	6.57	0	0.52	0	3.22	0
3	LOB	-80.43	-73.86	0	3.95	6.57	0	0.6	0	3.71	0
4	LOB	-73.86	-67.29	0	4.66	6.57	0	0.71	0	4.38	0
5	LOB	-67.29	-60.72	0	4.88	6.57	0	0.74	0	4.59	0
6	LOB	-60.72	-54.14	0	6.22	6.6	0	0.95	0	5.82	0
7	LOB	-54.14	-47.57	0	15.98	6.97	0	2.43	0	14.16	0
8	LOB	-47.57	-41	0	21.26	6.58	0	3.24	0	19.96	0
9	LOB	-41	-33.9	0	23.6	7.1	0	3.32	0	20.52	0
10	LOB	-33.9	-27.42	29.86	28.08	6.9	11.1	4.34	1.06	25.12	26.72
11	LOB	-27.42	-20.95	36	30.61	6.47	13.38	4.73	1.18	29.21	34.35
12	LOB	-20.95	-14.48	36	30.61	6.47	13.38	4.73	1.18	29.21	34.35
13	LOB	-14.48	-8	34.44	27.53	6.71	12.8	4.25	1.25	25.36	31.72
14	Chan	-8	-6.93	5.73	4.06	1.19	2.13	3.8	1.41	21.02	29.69
15	Chan	-6.93	-5.87	7.18	4.62	1.18	2.67	4.33	1.55	24.27	37.71
16	Chan	-5.87	-4.8	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
17	Chan	-4.8	-3.73	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
18	Chan	-3.73	-2.67	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
19	Chan	-2.67	-1.6	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
20	Chan	-1.6	-0.53	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
21	Chan	-0.53	0.53	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
22	Chan	0.53	1.6	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
23	Chan	1.6	2.67	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
24	Chan	2.67	3.73	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
25	Chan	3.73	4.8	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
26	Chan	4.8	5.87	8.28	4.84	1.07	3.08	4.54	1.71	28.04	47.96
27	Chan	5.87	6.93	7.18	4.62	1.18	2.67	4.33	1.55	24.27	37.71
28	Chan	6.93	8	5.73	4.06	1.19	2.13	3.8	1.41	21.02	29.69
29	ROB	8	11	11.09	10.58	3.09	4.12	3.53	1.05	21.16	22.17
30	ROB	11	13.32	2.99	6.22	2.55	1.11	2.68	0.48	15.04	7.24
31	ROB	13.32	15.65	1.29	3.75	2.55	0.48	1.61	0.34	9.07	3.12
32	ROB	15.65	17.97	0.26	1.41	2.48	0.1	0.61	0.18	3.52	0.64
33	ROB	17.97	20.29	0.08	0.7	2.32	0.03	0.3	0.12	1.85	0.22
34	ROB	20.29	22.61	0.04	0.48	2.32	0.02	0.21	0.09	1.28	0.12
35	ROB	22.61	24.94	0.02	0.26	2.32	0.01	0.11	0.06	0.7	0.04
36	ROB	24.94	27.26	0	0.06	1.66	0	0.03	0.03	0.21	0.01
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CONTRACTED CHANNEL SECTION

River Station 1962

CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 500 Year

			Left OB	Channel	Right OB	Total
E.G. Elev (m)	115.4	Element				
Vel Head (m)	0.27	Wt. n-Val.		0.048		
W.S. Elev (m)	115.13	Reach Len. (m)	17.4	17.4	17.4	
Crit W.S. (m)	113.29	Flow Area (m2)		117.61		
E.G. Slope (m/m)	0.002647	Area (m2)		117.61		117.61
Q Total (m3/s)	269.01	Flow (m3/s)		269.01		
Top Width (m)	35.39	Top Width (m)		35.39		
Vel Total (m/s)	2.29	Avg. Vel. (m/s)		2.29		
Max Chl Dpth (m)	4.48	Hydr. Depth (m)		3.32		3.32
Conv. Total (m3/s)	5229.1	Conv. (m3/s)		5229.1		
Length Wtd. (m)	17.4	Wetted Per. (m)		37.44		
Min Ch El (m)	110.65	Shear (N/m2)		81.53		
Alpha	1	Stream Power (N/m s)	1385.59	0	0	
Frctn Loss (m)	0.05	Cum Volume (1000 m3)	34.27	88.5	12.37	
C & E Loss (m)	0.07	Cum SA (1000 m2)	48.44	28.86	14.6	

		Flow dis.	*manual*
Left WS Sta.			-20.43
Left Flood Sta.		(data)	-20.43
Left Main Channel		-12.76	
Right Main Channel		7.76	
Right Flood Sta.		(data)	14.97
Right WS Sta.			14.97
L' (left)	7.67	L (left)	7.67
L' (Right)	7.21	L (Right)	7.21

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		23.16	14.68		
Main	20.52	227.5	89.97	4.38	2.53
Right		18.38	12.98		

Plan: PR_DOT Mad River Reach 1 RS: 1962 Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	Chan	-22.09	-20.22	0	0.01	0.23	0	0.05	0.06	1.18	0.07
2	Chan	-20.22	-18.36	0.32	1.06	2.09	0.12	0.57	0.3	13.2	4
3	Chan	-18.36	-16.49	3.16	2.8	2.09	1.17	1.5	1.13	34.85	39.3
4	Chan	-16.49	-14.63	7.25	4.54	2.08	2.69	2.43	1.6	56.5	90.25
5	Chan	-14.63	-12.76	12.43	6.27	2.09	4.62	3.36	1.98	78.04	154.63
6	Chan	-12.76	-10.9	18.31	7.69	1.94	6.81	4.12	2.38	102.78	244.66
7	Chan	-10.9	-9.03	19.98	7.98	1.87	7.43	4.28	2.5	110.87	277.61
8	Chan	-9.03	-7.17	20.74	8.16	1.87	7.71	4.38	2.54	113.4	288.22
9	Chan	-7.17	-5.3	21.47	8.33	1.87	7.98	4.47	2.58	115.8	298.47
10	Chan	-5.3	-3.44	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
11	Chan	-3.44	-1.57	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
12	Chan	-1.57	0.3	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
13	Chan	0.3	2.16	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
14	Chan	2.16	4.03	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
15	Chan	4.03	5.89	21.64	8.37	1.87	8.04	4.48	2.59	116.39	301.02
16	Chan	5.89	7.76	17.16	7.59	2.07	6.38	4.07	2.26	95.05	214.78
17	Chan	7.76	9.62	11.07	5.85	2.09	4.12	3.14	1.89	72.8	137.69
18	Chan	9.62	11.49	5.92	4.11	2.09	2.2	2.2	1.44	51.11	73.68
19	Chan	11.49	13.35	1.23	2.37	2.09	0.46	1.27	0.52	29.47	15.25
20	Chan	13.35	15.22	0.16	0.65	1.8	0.06	0.4	0.24	9.34	2.25
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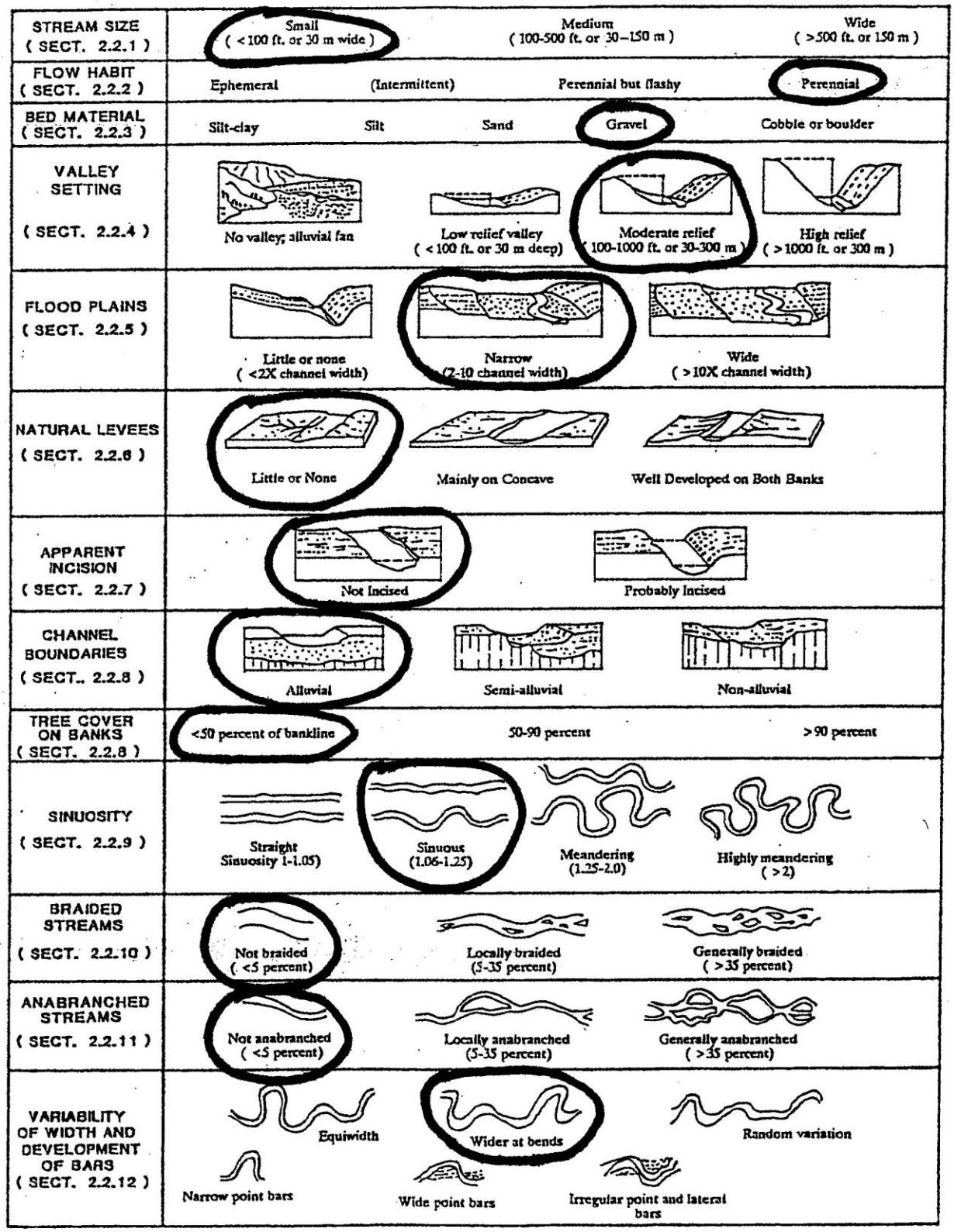
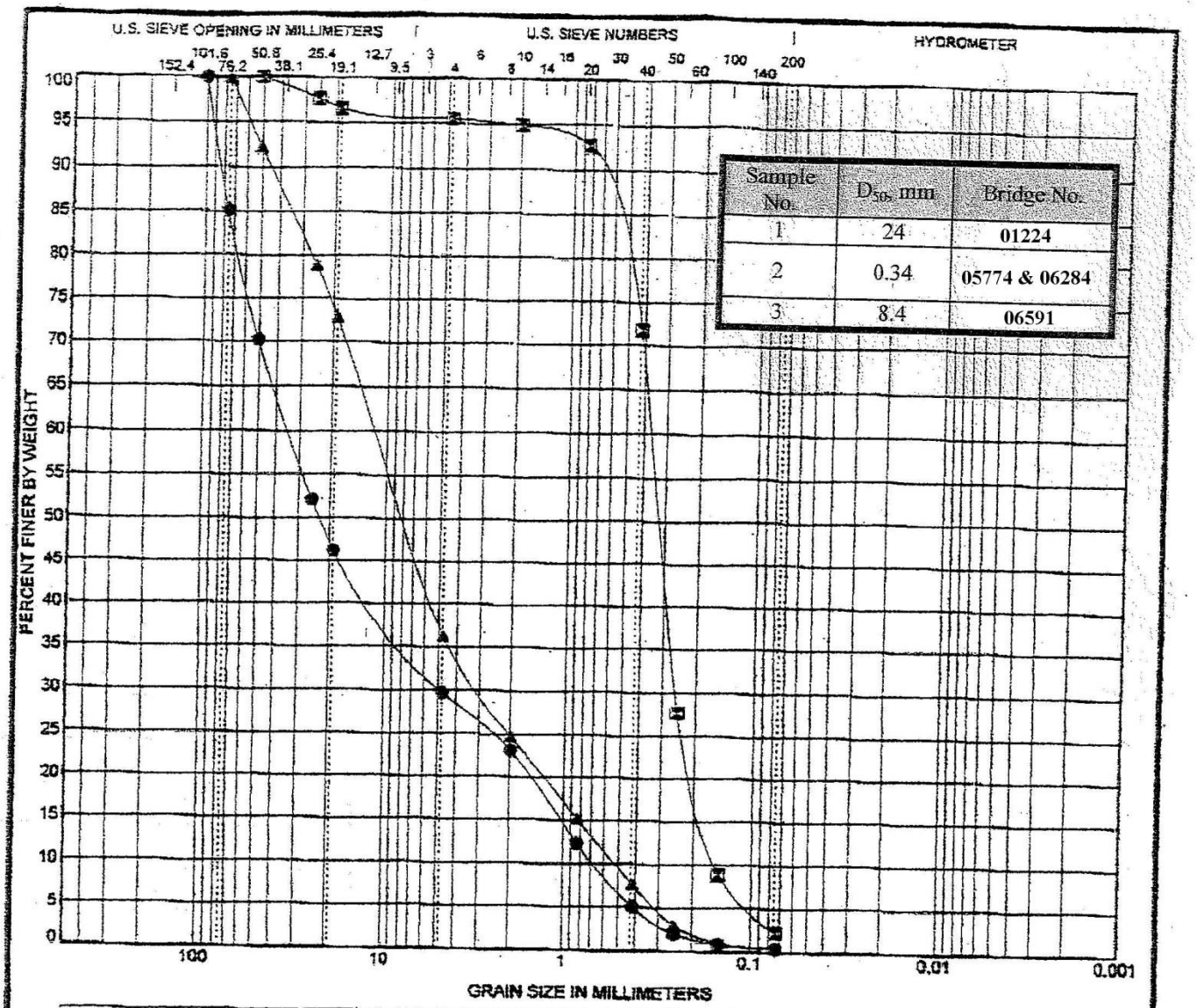
Appendix C:

Geomorphic Characterization
and
Grain Size Distribution

Mad River, Waterbury, CT
Proposed Bridge No. 06591



Geomorphic factors that affect stream stability



Sample No.	D_{50}, mm	Bridge No.
1	24	01224
2	0.34	05774 & 06284
3	8.4	06591

	COBBLES	% GRAVEL			% SAND		% FINES	
		COARSE	MEDIUM	FINE	COARSE	FINE	% SILT	% CLAY
●	14.9	32.4	14.3	14.8	18.0	4.7	0.4	
■	0.0	2.4	1.5	1.1	23.2	69.6	2.2	
▲	0.0	20.8	24.5	29.8	17.0	7.2	0.5	

	Expl. No.	Sample No.	Depth (m)	LL	PL	PI	Water Content (%)	Cc	Cu
●	TP	1					6.2	1.04	51.02
■	TP	2					21.2	1.17	2.38
▲	TP	3					5.6	1.46	22.48

Sample Description

●	Brown coarse to fine GRAVEL, little cobbles, little coarse sand, trace fine sand
■	Light brown coarse to fine SAND, trace coarse to fine gravel, trace silt
▲	Orange brown coarse to fine GRAVEL, little coarse sand, trace fine sand

Remarks:

HALEY & ALDRICH
Glastonbury, Connecticut

I-84 Reconstruction
Waterbury, Connecticut
State Project No.:

GRAIN SIZE DISTRIBUTION

Date: 12/17/2000

File No.: 91313-100

CONN DOT SIEVE 91313 FOR 91313 LAB GDT 12/20/00